A SCIENCE POLICY FOR CANADA

Available by mail from Information Canada, Ottawa,
and at the following Information Canada bookshops:

HALIFAX
1735 Barrington Street

MONTREAL
1182 St. Catherine Street West

OTTAWA
171 Slater Street

TORONTO
221 Yonge Street

WINNIPEG
393 Portage Avenue

VANCOUVER
657 Granville Street

or through your bookseller

Price: $3.00 Catalogue No. YC-282/1-02

Price subject to change without notice

Information Canada
Ottawa, 1972

A SCIENCE POLICY FOR CANADA

Report of the Senate Special Committee on Science Policy

Chairman: The Honourable Maurice Lamontagne, P.C.

Volume 2

TARGETS AND STRATEGIES FOR THE SEVENTIES

MEMBERSHIP OF COMMITTEE

The Senate Special Committee on Science Policy

The Honourable Maurice LAMONTAGNE, Quebec, *Chairman*
The Honourable Donald CAMERON, Alberta, *Vice-Chairman*

and The Honourable Senators:*

John B. AIRD, Ontario
Rhéal BÉLISLE, Ontario
Fred M. BLOIS, Nova Scotia
Maurice BOURGET, Quebec
Chesley W. CARTER, Newfoundland
Paul DESRUISSEAUX, Quebec
Louis de G. GIGUÈRE, Quebec
Allister GROSART, Ontario
J. Campbell HAIG, Manitoba
Harry HAYS, Alberta
Mary E. KINNEAR, Ontario
Daniel A. LANG, Ontario
Fred A. McGRAND, New Brunswick
John NICHOL, British Columbia
M. Gratton O'LEARY, Ontario
Orville H. PHILLIPS, Prince Edward Island
Joseph A. SULLIVAN, Ontario
Andrew THOMPSON, Ontario
Paul YUZYK, Manitoba

Quorum 8

MEMBERSHIP OF STEERING COMMITTEE

The Honourable Senators:

Donald CAMERON
Allister GROSART, *Chairman*
Maurice LAMONTAGNE
Andrew THOMPSON

---

*The following Senators also served on the Committee: The Honourable Hazen ARGUE (replaced on the Committee on September 9, 1969); The Honourable T. D'Arcy LEONARD (retired from the Senate on April 4, 1970); The Honourable Norman A. M. MacKENZIE (retired from the Senate on January 5, 1969); the Honourable M. Wallace McCUTCHEON (retired from the Senate on May 5, 1968); The Honourable Hédard ROBICHAUD (resigned from the Senate on October 8, 1971).

TABLE OF CONTENTS

Volume 2. Targets and Strategies for the Seventies

Index to be published in the last Volume.

FOREWORD

In December 1970 the Senate Special Committee on Science Policy issued the first volume of its report: *A Science Policy for Canada. A Critical Review: Past and Present*. The Committee described it in these terms: "This assessment has three perspectives. The first is historical; it describes how science policy developed in Canada and purposely emphasizes the weaknesses which have appeared at different periods since 1916. The second is international; it attempts to perceive how the Canadian science effort and its main components compare with those of other OECD countries, so as to expose weaknesses in Canadian participation in the international scientific and technological race. The third perspective is current and national; it summarizes the critical views on present conditions and the main suggestions presented to the Committee by Canadian representatives of the public and private sectors."[1]

This first volume was accorded gratifyingly widespread attention. We received several hundreds of comments from individuals and groups. The overwhelming reaction was favourable and included further positive proposals. A minority, composed mainly of pure scientists in universities, chose to criticize the review in strong and often emotional language.

This first volume was also the subject of a debate in the Senate. The Senators who took part were mostly members of the Committee and they attempted to deal with the points raised by our critics. Their speeches have been put together in a special reprint of the Senate Hansard entitled *Science Policy: Consideration of Volume 1 of Report of Special Committee*.[2]

Some commentators declared that the report was too critical of Canada's attempts at organizing a science policy. The Committee believes that its

words were no stronger than what can be found in practically all studies of Canadian science policy. Even as diplomatic and astute an organization as the OECD (the Organization for Economic Co-operation and Development) required forceful language in its recent report on Canadian science policy.[3] At one point, for example, it said:

> . . . the Federal Government increased and consolidated its own R&D activities in the decade 1950 to 1960 instead of stimulating non-government research centres.[4]

Elsewhere the report commented:

> The budget estimates of certain agencies of extreme importance to the future of Canadian science have thus been examined and passed by the Treasury Board without advice from the central organisations of national science policy.[5]

And at another point:

> Actually, the observer of Canadian science policy often finds himself on shifting and unknown ground. New structures that are not always readily and precisely defined, appear side by side with other organisations left over from another period.[6]

The OECD report also, incidentally, alluded to the response of the Canadian science community to an earlier review, the report of the Glassco Commission:

> As soon as they were made known, the findings of the Glassco Commission drew very strong protests from members of the scientific community and of the Federal agencies whose impartiality had been questioned. Many, no doubt, recognised that there were grounds for the criticism expressed by the Commission, but the majority protested against its recommendations.[7]

We suggest, in short, that the tone of the Senate Committee's criticism has not been unprecedented nor have some of those subject to criticism acted differently from the way they did in the past. But we would prefer to avoid any further debate on Volume 1 and instead to concentrate on the positive task of reconstruction that constitutes the topic of this second volume.

In the last chapter of Volume 1, which was a transition between critical analysis and positive recommendation, we attempted to justify "the need for an overall science policy". Strong support for this claim, if it was needed, was given by a recent study of the science policies of 29 European countries, carried out under the auspices of UNESCO. This was one of its main conclusions:

> In almost every case, there has clearly been an important change in the concept of national science policy, which is no longer confused with the more or less

spontaneous existence of a scientific activity in the various national institutions for research and teaching, even if that activity is highly developed. It is becoming increasingly obvious that the need for a deliberate "national policy" relating both to R&D and to technological innovation is nowadays unavoidable. Moreover, it is clear that the different modern conceptions and methods of study, organization and management, which are becoming increasingly prominent in the various areas of activity of contemporary society, must also be introduced into R&D so as to ensure a scientific approach to its various and complex problems. All the science policy and R&D institutions in a given country, together with the researchers and their instruments of work, finally come, in fact, to be regarded as a "system", in the sense in which that word is understood by data processors and specialists in dynamic programming.[8]

At the same time views similar to the Senate Committee's were also being developed elsewhere. The Committee raised two main points in that transitional chapter. One, it emphasized that an overall policy was needed to complement the diffuse and decentralized approach that had been followed in Canada: "It must be emphasized again that the role of an overall science policy, like that of a macro-economic policy, is not to replace specific policies but to support them with a basic framework, broad terms of reference, and criteria to assess their efficiency."[9]

Two, the Committee urged the development of a "second generation science policy" centred around collective social needs, as opposed to the first generation, which was mainly preoccupied with military and economic objectives. We stressed the R&D gaps in such areas as education, urban living, poverty, health, pollution, the negative impact of technology, leisure, and "human maladjustment to a rapidly and constantly changing technological and social environment". We concluded: "A 'second generation science policy' must meet all these problems."[10]

In April 1971 the OECD issued a report prepared by an *ad hoc* group under the chairmanship of Dr. Harvey Brooks of Harvard and composed of eight full members and two associates, including Dr. Alexander King, Director-General for Scientific Affairs at the OECD—all experts of international repute in the field of science policy.[11] This eminent group put special emphasis on these same two main themes of the last chapter of Volume 1. When we published it, last December 1970, the concept of a complementary overall science policy was far from being universally accepted. The OECD group, however, describes and rejects the pluralistic or micro approach in terms much the same as those we used:

In the pure form of the pluralistic approach, resources are assigned to each policy sector as a whole—e.g., defence, health, agriculture, transportation,

housing, social welfare—and the appropriate level of R&D for each sector is then determined in competition with capital investments and service expenditures in the same field. The overall science policy is then the sum of the policies arrived at, in a first approximation, independently for the individual sectors.[12]

(We wrote that "national science policy had been reduced to the mere sum of specific sectoral policies",[13] and that deficiencies had appeared mainly "because the government has relied exclusively on a series of limited and isolated science policies, without having an overall view of what was going on and a global strategy for what had to be done."[14])

The OECD group concluded:

We have felt it necessary to discuss this issue at some length because we have found a disposition in many countries to regard the centralized and pluralistic models as mutually exclusive alternatives and to be debating a choice between them in their own structures . . . . we consider an either-or choice undesirable. . . .[15]

(The Committee said: "It has become a major responsibility of government in this age of the scientific revolution to ensure that society gets the maximum benefits from science and technology at a minimum cost. To do this the government needs not only science policies by sectors, such as health, transportation, energy, and agriculture, but also the macroscopic approach that only a coherent overall science policy can provide. These two approaches must complement each other."[16])

On the second point, the need for a second generation science policy, the OECD group stated:

The diversification and intensification of collective needs and aspirations are among the most lasting and most far-reaching consequences of economic growth. The satisfaction of such collective needs will occupy an increasing fraction of society's attention in the 1970's and beyond, and will thus constitute a growing dimension of science policy.[17]

(We commented: "But as we try to readjust our R&D effort to serve this national purpose [economic growth] more effectively, we must also develop a 'second generation science policy'. It will be centred around the good life rather than the 'goods life,' to use Lewis Mumford's expression. We cannot spend the next decade totally preoccupied with the development of basic science and market-oriented technology. We must also organize our national science effort so that it can make its full contribution to the solution of the social problems that will otherwise soon cripple our society."[18])

In numerous details the international group of science policy experts reporting to the OECD pursued a course very similar to that which we had simultaneously or earlier followed in Canada. That does not make us right; but in the face of criticism from some areas of the Republic of Science in Canada it is a form of support for the positions we took, some assurance that we had not fallen into a nest of connected misinterpretations and gaucheries, and an encouragement to us in presenting the recommendations that follow.

This second volume of the Committee's report bears the subtitle, *Targets and Strategies for the Seventies*. It deals only with the general background and framework of an overall science policy and with targets and strategies for basic research and industrial research, development, and innovation. It covers essentially what we have described as the "first generation of science policy". The Committee reported in Volume 1 that Canada had failed in this respect and added:

> We need an overall science policy and a global strategy to correct the situation. Indeed, perhaps more than ever before we need to create the proper technological environment for the development of the productive sector.[19]

This second volume represents an attempt "to correct the situation". As such, it stands by itself. It shows the wide scope that this "first generation of science policy" must have to attain its objectives. Furthermore, it contains a number of suggestions and recommendations that merit separate and urgent consideration, in our view, because they involve drastic changes in the intensity and orientation of the Canadian effort devoted to science, industrial technology and innovation. The reaction they will cause, the extent to which they will be accepted or rejected, will, of course, influence the views of the Committee on the reorganization of government institutions that will be presented later.

Subsequently the Committee will report to the Senate on targets and strategies of the "second generation of science policy." We will cover the broad area of social innovations designed to meet collective needs and problems, such as health care, pollution, education, and urban living, as well as the applied research and development programs required to improve the social innovative process. This area of science policy is recent but so important that it deserves separate consideration and debate.

The Committee will also report on the reorganization of government institutions with specific or overall responsibilities in the formulation and implementation of science policy. The Committee believes that there is an advantage in separating the consideration of targets and strategies from the

examination of the changes needed in government administrative mechanisms and machinery. It is often tempting to make organizational changes and to set up new institutions in the hope of solving new policy problems. But this process may be easier than useful. The Prime Minister warned against this danger when, in his speech on the Government Organization Bill, he quoted Petronius Arbiter:

> We trained hard—but it seemed that every time we were beginning to form up into teams, we would be reorganized. I was to learn that later in life we tend to meet any new situation by reorganizing, and a wonderful method it can be for creating the illusion of progress.[30]

The Committee believes that the Canadian government should not rush in to make organizational changes or create new agencies on the spur of the moment in the field of science policy, without first having considered and decided the broad targets to be achieved and the strategies to be followed. The obvious reason why organizational changes should come only after such a review is that institutions and the administrative mechanisms relating them should be specifically designed to meet the objectives and to implement the broad strategies that have been selected. It may be not only futile but most undesirable not to follow this logical and chronological order. Institutions, especially in the public sector, have a remarkable capacity to survive and once they have been created, it is not easy to destroy them or even to change them. Thus, the Committee strongly urges that any important organizational changes relating to science, technology and innovation be delayed until the specialized communities immediately concerned have had the opportunity to react to the main recommendations contained in this volume and until the government itself has determined whether or not it should accept them.

The Committee supposes that this second volume will probably generate at least as much debate as the first. It hopes, however, that discussion will not result in inaction and will not prevent a drastic re-orientation of the overall targets and strategies of Canada's science effort. Similar attempts have failed in the past. This report offers a new opportunity that may be the last in the 1970's. If it is missed, Canadians could realize in the 1980's that it is too late to make the basic readjustments that are urgently needed even today. As a country, we can now lead the world in establishing a sound basis for a coherent science policy. The Committee hopes that Canadians, including their governments and the specialized communities of science and technology will face this challenge positively and will not hesitate to innovate where old strategies and traditions have become outmoded.

NOTES AND REFERENCES

1. The Senate Special Committee on Science Policy, *A Science Policy for Canada; A Critical Review: Past and Present,* Ottawa, 1970, p. 14.
2. Published by the Queen's Printer for Canada, No. 95218.
3. OECD, *Reviews of National Science Policy: Canada,* OECD Publications, No. 26,223, Paris, 1969.
4. Ibid., p. 48.
5. Ibid., p. 77.
6. Ibid., p. 80.
7. Ibid., p. 63.
8. UNESCO, *National Science Policies in Europe,* Science Policy Studies and Documents, No. 17, 1970, p. 50.
9. *A Science Policy for Canada, op. cit.,* p. 281.
10. Ibid., p. 283.
11. OECD Secretary-General's Ad Hoc Group on New Concepts of Science Policy, *Science, Growth and Society, a new perspective,* OECD, Paris, 1971.
12. *Science, Growth and Society, op. cit.,* p. 66.
13. *A Science Policy . . ., op. cit.,* p. 185.
14. Ibid., p. 275.
15. *Science, Growth and Society, op. cit.,* p. 68.
16. *A Science Policy . . ., op. cit.,* p. 282.
17. *Science, Growth and Society, op. cit.,* p. 59.
18. *A Science Policy . . ., op. cit.,* p. 283.
19. Ibid., p. 282.
20. Commons Debates, Feb. 27, 1969, p. 6017.

11

CHALLENGES AND OPPORTUNITY FOR SCIENCE AND TECHNOLOGY

The standard and quality of life in this country will be largely determined by the way in which the people and their institutions respond to the prospects and perils of the application of science and technology. Because the funds expended for research and development are predominantly public monies voted by Parliament, Canada's future will be greatly determined by the effectiveness of the government's strategy and machinery for expending these funds.

This conviction of the Senate Special Committee on Science Policy was steadily strengthened at its hearings and by its continuing discussions with a large number of Canadian individuals and groups in the past few years. The same conviction was expressed to us in each of the eight countries the Committee visited. It is clear that all governments today, at least in advanced countries, regard their expenditures on science, technology, and innovation as a concern of high priority.

During its hearings the Committee became convinced that science and technology have a significant impact on virtually all contemporary events, activities, and attitudes, from international relations to industrial innovation and student unrest. Science policy, impinging as it does on nearly every activity of government, is therefore a central and vital facet of a government's policy portfolio.

For at least 25 years leading political figures, scientists, historians, and philosophers in countries throughout the world have testified to the multifold opportunities science and technology offer a nation for the improvement of the well-being, safety, and personal development of its citizens. At the same time an immense concern about the application of science and technology

has arisen all around the globe. People are worried, for example, about the rapidly growing cost of the equipment required for scientific research (e.g., facilities for atomic research); the deleterious side-effects of technology (e.g., pollution); and the monumental problems associated with affluence and urbanization (e.g., waste disposal), most of which are direct or indirect effects of our use of technology. A government's science policy must therefore be responsive to the opportunities and challenges presented by science and technology.

This chapter is intended to serve as a general introduction and background to make the general public more aware of the crucial importance of science and technology for the future of Canadians and mankind in general. It does not claim originality. Instead, it summarizes assessments and forecasts of scientific and technological changes and their economic and social impact made by well-known experts. It must be noted here that experts often vary widely in their assessment of new problems; for example, with regard to the radiation hazards of nuclear reactors. Experts in science policy fields have been seen to have opinions ranging from hysteria to bland unconcern. A conflict of experts should not mean that the subject be dropped until the experts all agree—for then it would be too late to meet the problem. Rather the government must institutionalize a system of confrontation, for example as in the judicial system, whereby conflicting expert opinion, including that from all vested interest groups, can be heard. This process should be as visible as possible to the public, and the public and its representatives must be enabled to participate. The latter point is discussed more fully further in the report.

It is admittedly a rather extended recitation of some of the perils and potentials of the age. It may appear to some that more emphasis has been given to the perils than to the potentials. This may well be true, but we need only comment in rebuttal that perils must be effectively evaluated and dealt with otherwise potentials might well remain unrealised. The Committee is convinced, however, that a Canadian national science policy can only be successfully developed in the scientific, technological, and geographical context, and that is daily growing more extensive.

THE SCIENTIFIC AND TECHNOLOGICAL REVOLUTION

The peoples of the developed world today live in an era that grew out of the Renaissance and that increasing numbers of historians call the scientific revolution.[1] No other era has been as deeply affected by this revolution as

has the 20th century. Indeed it is now felt that through continuing developments in science and technology we live in an age of permanent revolution, in which our understanding of the past and our expectations of the future undergo continuous, rapid change.

The revolution began in the period of scientific growth between 1500 and 1700. Many historians agree with Professor Herbert Butterfield that, for the western world, the scientific revolution "outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the rank of mere episodes."[2]

What is peculiar to the world of the scientific revolution, and this is especially so today, is the belief that scientific knowledge can be used by man to master nature and exploit it for his own ends. Francis Bacon (1561-1626), whose outlook still colours our attitude toward science, was not the first spokesman for such an approach but he was the most eloquent and convincing advocate for this viewpoint in European history. In Bacon's view the new science and the new technology were to go hand in hand as the servants of human needs:

> . . . knowledge is not to be sought either for pleasure of the mind, or for contention, or for superiority to others, or for profit, or fame, or power, or any of these inferior things; but for the benefit and use of life . . . .[3]

The Baconian spirit was very influential among the fellows of the Royal Society, founded in London in 1660. It has been estimated that during the first 30 years of the society's existence nearly 60 per cent of the problems it handled were prompted by practical needs of public use and only 40 per cent were problems of pure science.[4]

The Baconian spirit was reflected also in the writings of René Descartes (1596-1650), one of the greatest scientists and philosophers of the scientific revolution:

> It is possible to attain knowledge which is very useful in life, and instead of that speculative philosophy which is taught in the Schools, we may find a practical philosophy by means of which, knowing the force and the action of fire, water, air, the stars, heavens, and all other bodies that environ us, as distinctly as we know the different crafts of our artisans, we can in the same way employ them in all those uses to which they are adapted, and thus render ourselves the masters and possessors of nature.[5]

One after another the great majority of scientific societies, scientists, and other thinkers accepted and emphasized Bacon's views in the three centuries of explosive growth of the scientific and technological revolution in the western world. In countries touched by this revolution, science grew more rapidly

than any other human activity,[6] so that the present situation can be described in dramatic terms:

> – Of every eight scientists who ever lived, seven are alive today.
> – Total R&D expenditures in the United States (public and private) approximated $25 billion in 1968, and are growing at the rate of about one billion [dollars, or four per cent] annually. In 1940, the figure was less than one-fourth of a billion. The annual expenditure is now more than the total of federal expenditures for science from the Revolutionary War through World War II.[7]

In Canada, total expenditures on R&D increased by an average 15 per cent a year in the quarter century from 1940 to 1967, or from about $20 million to more than $800 million annually.[8] If present trends continue they can be expected to rise to $4 billion by 1980.

The scientific and technological revolution has until recently been confined to the West. For example, in commenting on its effect on the developed countries, Michael Harrington states that "The modern West distinguished itself from other cultures by its Faustian assault upon reality, its relentless ambition to remake the very world. In the matter of a few hundred years, this drive created an industrial civilization and a standard of living that became the envy, and model, of the entire globe."[9]

The West's monopoly on scientism is disappearing however. If the words of Chairman Mao are any indication, the Baconian spirit is being driven home to the hundreds of millions of readers schooled in his little red book; for example, one quotation reads:

> Natural science is one of man's weapons in his fight for freedom. . . . For the purpose of attaining freedom in the world of nature, man must use natural science to understand, conquer and change nature and thus attain freedom from nature.[10]

The most notable development of the scientific revolution outside the West has been in Japan, a country which since World War II has used science and technology to support a sustained economic growth rate unequalled by any other nation, until it is now the world's strongest technologically developed country after the United States and the Soviet Union.[11]

It has been estimated that the world is now devoting $50 billion annually to research and development. The exponential rate of growth these outlays have experienced since the beginning of the revolution will inevitably have to decline but the best forecasts available indicate that in absolute terms expenditures are bound to continue to increase rapidly in the foreseeable future. As more countries attempt to get the maximum results from these

expenditures, it is no exaggeration to say that this substantial science effort is the unique and characterizing feature of contemporary society and is bound to have a deep impact on the society of tomorrow. If present trends continue the world, especially in advanced countries, is condemned to rapid and radical change in all sectors of human activity.

SCIENCE AND TECHNOLOGY FOR MAN'S BETTERMENT

Today it seems important to distinguish sharply between science, technology, and innovation even though it is obvious that they grew together. The distinguished science historian Thomas S. Kuhn has declared that "As a first approximation, the historian of socioeconomic development would do well to treat science and technology as radically distinct enterprises, not unlike the sciences and the arts",[12] arguing that "Science, when it affects socioeconomic development at all, does so through technology".[13] Only at the end of the 19th century were science and technology tightly wed, in two industries in Germany, the chemical dye industry and the early electrical industry. Many misconceptions arise from the illusion that science is a prime cause of material progress and from efforts to make it so. The Committee drew a clear distinction between science, technology, and innovation in Volume 1. We stated that the "natural fruit of science [knowledge] is always good and its impact on society can only be beneficial."[14] We also pointed out that technology can be good or bad or both when it is transformed into innovations. This quality of technology has been noted by Walter Orr Roberts, a former president of the American Association for the Advancement of Science (although in our view he inexactly used the word *science* for *technology*):

> Nearly every advance of science has two faces. One smiles on us and lifts the aspirations of man; the other scowls sternly on all future hopes. For the miracle of the automobile there is the rising scourge of car-born air pollution that threatens to choke our Bosnywashes (the giant Boston-New York-Washington megalopolis). The advance of urbanism, made possible in part by the miracles of air-conditioning and food transportation, brings us befouled rivers, vanishing privacy, and lives full of strain and tension. For all the miracles that atomic energy has wrought in medicine, industry and power generation, there hangs over us the spectre of nuclear war.[15]

It is interesting to note that people who write about technology generally stress one or other of the two faces according to their own optimistic or pessimistic views. The Committee intends to present the two reactions so as to give a more balanced assessment of the net impact of technology on society.

Descartes's vision over 300 years ago that by the application of science men would become "the masters and possessors of nature" and Bacon's view that "human life be endowed with new discoveries and powers" have been realized to a degree that would probably startle them. The development of science and technology has helped produce the fastest rate of economic growth in the world's history. It has brought to those fortunate enough to share in their benefits a unique affluence, freedom, and improvement in living conditions.

The development of technology has had the overall effect of increasing productivity in the factory and on the farm. This has led to a rising standard of living, a continuing trend away from working with things (the goods industries) toward working with and for people (the service industries), and increasing leisure.

In the home, drudgery has been greatly reduced by means of machinery, developments in food technology, synthetic fibres, and new compounds for cleaning. The man-made environment can be made more stimulating and attractive by the variety of opportunities afforded by improved materials, paints, dyes, and means of design; we must now take the opportunity of focusing these improved capabilities onto the rebuilding of the cities.

The epidemics that ravaged human communities in the past[16] have become medical rarities wherever existing knowledge is vigorously practised.[17] Microbiology combined with clinical research has drastically reduced the danger of poliomyelitis, smallpox, diphtheria, typhoid fever, plague, and malaria. The mortality rates of infectious diseases have been brought down to a very low level, particularly among children and young adults, and as a result life expectancy at birth has risen to unprecedented levels—approximately double what it was in the days of Bacon and Descartes.

According to one writer,[18] in the normal course of events a continental rubella epidemic would be expected in North America some time in the early 1970's.[19] On the basis of past experience, it would almost certainly cause more than 50,000 babies to be born dead or deformed, and at least 20,000 survivors would need special care all their lives. Fortunately, rubella vaccines show every promise of preventing such an epidemic.

New developments in science and technology continue to be applied to the preservation and protection of human life. The laser is used in delicate eye operations, the linear electron accelerator is turned against tumours, and the Cyclotron is being used experimentally to produce short-lived radioactive isotopes to assist in diagnosis. Until a few years ago all these devices were associated only with physics research but more and more they are being used in cancer radiotherapy. According to one expert the increase in power of

these high intensity sources of x-ray and gamma-ray energy has resulted in the fact that "some 90 per cent of early cancers of the larynx can be cured by radiation, sparing the patient from disfiguring surgery and the loss of his voice".[20] Radiotherapists are now working on replacing x-rays by the new subatomic particle, the pi meson. The list of medical innovations is a long and constantly growing one, and Canadian medical science is making significant contributions to it. For example, Dr. Philip Gold of McGill University has found a specific antigen in tumours of the bowel, a leading cancer killer, that can be found in the blood and tests to date on 1,500 patients have proved 95 per cent reliable in detecting cancer of the colon and rectum; in many cases detection occurred long before it would have been visible by x-rays.[21] Dr. T. H. S. Chang, another Montreal-based life scientist, is working on what appears to be a promising development for a portable dialyzer or artificial kidney.

Science has brought a revolutionary change to agriculture. In many countries new types of rice and wheat with many times the yield per acre of previous strains have brought about a "green revolution". New sources of protein have recently been developed by fish farming and mariculture, the production of diet-supplementing protein from whole fish, and the conversion of petroleum to protein cattle feed. Food processors already possess the technology for fabricating vegetable protein into what is indistinguishable from meat in appearance, texture, and taste.[22] A Japanese company has developed a process using wheat protein.[23] One nutritional scientist states that in the next two or three decades such developments will mean that food may "be removed altogether as a limiting factor to population".[24] New developments in food science and technology are commonly reported in today's press; for example over 25 major U.S. oil companies are attempting to develop an economical way of producing protein from petroleum.[25] According to Dr. Magnus Pyke the time has now come when "The scientific knowledge of how to make food synthetically is already available—and here I am referring to chemical synthesis and not merely to the processes for converting one existing food product into something different, . . . several individual amino acids are already manufactured and there would be no major problem in synthesising the 20-odd which comprise the components of beef protein or egg-white."[26]

Transportation technology has given people freedom of movement unknown in past times. Today's aircraft cross the Atlantic in about one 500th of the time taken by Jacques Cartier. Air travel is becoming safer, faster, cheaper, and available to growing numbers. In fact "The era of global mass travel is just beginning. . .".[27]

Communications technology has transformed man's environment. Television is fast becoming the world's main entertainment and information medium. It also provides an unprecedentedly potent means of instruction. The technical prospects of television are dramatic: for example, a single conventional television channel will one day be able to carry the contents of a thirty-page newspaper each second. As a result one channel could transmit—on a continuing basis, as it is published—every word and illustration printed in every newspaper, magazine, journal, and book throughout the world.[28] Dr. A. G. Hill estimates that within twenty years, "With only modest improvements in cables and television sets, as many as eighty-two television channels or their equivalent could be available in the home for a wide variety of services."[29]

Already we have seen new uses of technology that may well revolutionize education in the future. For example, in Great Britain on one day in January 1971, British university enrolment suddenly increased by more than 40 per cent as 25,000 men and women attended their first Open University orientation lectures via their TV sets. This development is a well planned and staffed educational endeavour and not simply a sophisticated version of educational TV, yet the cost for each student is still only one third of what it is for a student in one of Britain's residential universities.[30] There are reasons other than the merely technological or economic for the development of open universities or universities accepting work performed off-campus; the latest report of the Carnegie Commission on Higher Education, for example, points out that off-campus education can not only save enormous sums but can also inject new life into education.

Soon, it is estimated, with video tape and national computer hookups it will be possible to broadcast course material presented by the best lecturers to students throughout the nation.[31] The obvious possibilities of video cassettes (an estimated $2 billion market in North America by 1980) have led to active technological developments of various systems. Already, in France, Europe's first medical journal is being distributed in the form of video-cassette.[32]

The broad potential of computer-video instruction is not so clear. In 1968 one noted expert, Dr. Patrick Suppes, declared: "One can predict that in a few more years millions of school children will have access to what Philip of Macedon's son Alexander enjoyed as a royal prerogative: the personal services of a tutor as well-informed and responsive as Aristotle".[33] By 1970 he had toned this down, noting that such educational techniques were "As a general approach to mass education . . . clearly prohibitive economically".[34] The study of the use of educational technology shows that there are more

blocks to its progress than just the economic; for example, reflecting on the U.S. school system, Professor Anthony G. Oettinger wrote that "The formal educational system is bound to society in a way that is almost ideally designed to thwart change. Little *substantive* technological change is therefore to be expected in the next decade".[35] We cannot afford to ignore the complex challenge of incorporating technically-based innovations.

Space technology has provided satellites that allow rapid communications on a global basis; in some cases, for example educational TV in large under-developed regions, satellites are the cheapest communications system available. This is in fact a good example of the influence of technology on international affairs. As one observer suggested: "In the 1970's, some highly advanced nations will have the technological capability for beaming television programs directly into the receivers of the less developed world. . . . It is conceivable that in the 1980's the superpowers will increasingly project themselves through television broadcasts directly into the receivers of the more advanced countries, such as those in Western Europe".[36]

Observation satellites are already assisting in improving weather forecasting and the long range economic benefits of this will be sizeable.[37] Large economic benefits will also come from the use of satellites for geophysical exploration and resource inventory; the international aspect of technology is demonstrated by Canada's participation in the U.S. ERTS satellite.[38]

The development of nuclear power has already removed the fear of the eventual exhaustion of energy sources. Even more spectacular are the promises of future energy technologies. One specialist, considering the implications of the breeder nuclear power plant, writes that this is "not merely another energy source . . . a new dimension in man's horizon is being unfolded, with far reaching social and political implications".[39] If this forecast proves correct then there will be large changes in the chemical industry and in agriculture. The cheap power could be used to desalinate sea water and produce nitrogen fertilizers and together these could make barren deserts flower.[40] Beyond the breeder reactor some scientists see an even cheaper source of power in nuclear fusion, the process of the H-bomb; a Soviet scientist recently forecast that a prototype fusion reactor could be generating electricity by the 1990's.[41] U.S. experts predict that a prototype reactor could be operating in 10 to 50 years' time depending on the financial support it is given.[42]

There has been no brighter development in science in recent years than the advance of molecular biology. One notable milestone was the discovery of the structure of DNA and the genetic code by James D. Watson and Francis Crick, a breakthrough that has been compared with the breaking

of the atom or the publishing of Darwin's *Origin of Species*. It marked the point of fruitful maturation for molecular biology and, ever since, startling possibilities for man's betterment have come within reach. Recently developed techniques show there is a real possibility of developing plants that can fix nitrogen out of the air and thus remove the need, as well as the social and economic burden, of artificial fertilizers.[43]

Now it is thought that man may be able to wreak such changes on himself. If so, he is coming close to what Teilhard de Chardin described as "The dream upon which human research obscurely feeds . . . grasping the very mainspring of evolution, seizing the tiller of the world."[44] Or as Caltech biologist Robert Sinsheimer puts it:

> For the first time in all time, a living creature understands its origin and can undertake to design its future.[45]

This new development in the life sciences holds the promise of curing such dread diseases as cancer, correcting the genetic defects that perhaps account for some 50 per cent of human ailments, expanding the abilities of mind and body, and ameliorating the erosion of old age.

The new knowledge of human genetics combined with the developing techniques of microsurgery and human cell manipulation have suddenly presented possibilities of human reproduction that will threaten the moral and social foundation of society. It appears possible that man can be produced by cloning, that is, by culturing cells so that they grow into a full-sized replica of the original or by some other asexual form of reproduction. Surrogate mothers could give birth to children identical with any existing person. There is even talk of mechanical wombs.[46]

Probably the most far-reaching and important technological development has been the computer. The computer is ten million times faster than a man calculating by hand, and it not only eliminates much clerical drudgery but aids in the study and mastery of complex systems and processes.[47] Computer-based information systems promise to allow managers to make faster and better informed decisions. One political scientist has defended the thesis "that the availability of comprehensive information systems can today improve the quality and rationality of decisions reached in the political process"[48] and has predicted that by the mid-1970's computer technology will be adapted for the personal use of government leaders, elected representatives, and public officials. This development would certainly also widen the participatory base for political decision making.[49]

Since the first computers in the mid-1940's their size has decreased by a factor of 100, the cost has decreased by a factor of 100,000, and the speed

has increased by a factor of 100,000.[50] Improvements are still being made at a rapid pace and this will bring the benefits of computers to every desk and eventually to every home.[51]

Aristotle defended human slavery and could foresee its overthrow only when the "myth" of automation became a fact, when "a shuttle should weave of itself, and a plectrum should do its own harp playing".[52] Automation (which uses self-correcting machines) and cybernation (which makes the automated machines capable of responding to all foreseeable contingencies by connecting them to computers) are now turning myth into reality. The computer, therefore, especially when combined with the future prospect of cheap energy, promises to free us from the slavery of servile work and to extend our intellectual and creative capacity. Bacon and Descartes were correct in predicting that the scientific revolution they helped to begin would greatly improve the physical lot of man.

The majority of Canadians living today can expect to see the year 2000. Some developments that a group of scientists predict will occur before then:[53]

Economically useful desalination of sea water.
Automated language translators.
New synthetic materials for ultra-light construction.
Implanted artificial organs made of plastic and electronic components.
Controlled thermonuclear power.
Economic feasibility of synthetic protein for food.
Increase by factor of ten in number of psychotic cases amenable to physical or chemical therapy.
General biochemical immunization against bacterial and viral diseases.
Widespread use of sophisticated teaching machines.
Automated libraries looking up and reproducing copy.
Widespread use of automatic decision-making at management level for planning.

These are just some of the astounding benefits that the permanent scientific revolution may bring during the next two or three decades. This is the bright side of the coin of science and technology.

TECHNOLOGY AND THE THREAT TO MAN

There is also a destructive side to technology that was not foreseen by the prophets and founders of the scientific revolution. Or, it would be fairer to say, they assumed man would utilize knowledge more carefully, that full understanding would always precede action. Bacon put "experiments of

light" ahead of "experiments of fruit". "Although Bacon believed that his new method of discovering knowledge would revolutionize the material condition of mankind, he insisted that 'works themselves are of greater value as pledges of truth than as contributing to the comforts of life'."

"Yet", as Harvey Brooks points out, "although society adopted Bacon's revolution, it has never quite believed in it. It has always hoped to get the fruits with the light."[54] Full understanding has not always accompanied application. The horror of deformed babies followed the application of thalidomide. The technological achievement of personal mobility has been accompanied by limitations forced on children; almost every second day Los Angeles pupils are denied outdoor recess because of the fear that they may breathe too deeply of the air polluted by automobile exhaust.[55] Technology has also had indirect unwanted effects. The improvement of productivity on the farms has brought the rapid growth of urbanization and the consequent problems associated with human waste. The development of many new products and the improvement of industrial productivity have created an abundance of material goods and with it the serious side problems of pollution and waste disposal. As René Dubos recently noted: "Since we make so little effort to study the long-range effects of technologic innovations, we are in fact practicing, not by intention but by inaction, a kind of biological warfare against nature, ourselves, and especially our descendants."[56]

The Rhine which flows past the potash mines of Alsace and through the industrial Ruhr Valley to the North Sea is now known as "Europe's Sewer". Even more startling is the recent claim that the Mediterranean, that body of water that helped nurture the birth and development of Western civilization, is in imminent danger of dying. In Italy, Professor Mortarino is quoted as saying that "Our coastal waters are already dead as a source of food and as an amenity".[57] According to Thor Heyerdahl the Atlantic itself was found to be noticeably polluted during the voyage of Ra II; Heyerdahl writes that "On a daily survey, we observe the shocking pollution of the ocean. Blobs of solidified oil . . . turn up frequently together with plastic bottles and other human refuse. At times the water lies hidden beneath soapy foam and oily liquids shining in all colors."[58]

The *New York Times* has commented harshly on conditions in the U.S.A.:

> Americans have "jettisoned" their wastes into the waters and the skies. The rivers are cesspools and the cities slums. In three short centuries—too brief a time to be measurable on the scale of the universe—the inhabitants of this land have fouled their nest to the point where it would take the major

part of the country's money and resources and the redirecting of all its priorities to restore what has been spoiled.[59]

The pollution of Canadian waters is increasingly a matter for concern. The Speech from the Throne which opened the second session of the 28th Parliament noted:

> The evidence of past failure to rehabilitate our water resources is there for all to see—befouled water, despoiled beaches, rotting marine vegetation, and diminished fishing.[60]

The *New Scientist* recently stated: "A particularly disturbing fact is that Alaskan crude oil is one of the most toxic of all (crude oils) at the sort of temperatures that pertain in the Arctic. . . . A potentially worrying aspect is that Alaskan crude oil seems to be one of the most highly toxic of all at temperatures just above freezing point. . . . If Alaskan oil did hit an Arctic coast before the highly toxic lighter fractions had a chance to evaporate, it could do tremendous ecological damage."[61] If this is so then caution over possible oil pollution in the Canadian Arctic is fully justified.

Examples of new forms and instances of pollution continue to be publicized. For example:

> The St. Lawrence River is in danger of becoming a fetid, stagnant body of water unsuitable for anything except continued use as a sewer.[62]

Pesticides and fungicides are also playing a role. In 1968 some Swedish lakes contained enough mercury from chemical seed dressing to cause the government to greatly restrict the consumption of fish.[63] The Alberta government cancelled the 1969 hunting season for Hungarian partridges and pheasants as they were found to contain ten times as much mercury as was recommended by the World Health Organization.[64] This came about because the birds ate seed grain treated with a mercury compound to resist insect pests and fungus. There have been many more instances of prohibitions forced by mercury seed dressing.[65] The most startling event of all was the press release on March 20, 1970, issued by a Norwegian, Norvalo Fimreite, a graduate student at the University of Western Ontario, stating that he had measured in fish caught in Lake St. Clair an amount of mercury 14 times greater than the accepted limit.[66] Fimreite was conducting research with financial assistance from the Canadian Wildlife Service and his findings helped trigger off the mercury pollution search in Canada and the United States. What disturbs the Committee is the fact that Canada's mercury pollution was for so long unknown to those responsible for such matters. It

was only by almost accidental good fortune that an interested graduate student found the awful facts—and this a decade after more than 100 Japanese suffered death or severe disabling from eating mercury contaminated fish taken in Minamata Bay.[67]

And it has to be noted that it is not only mercury but all heavy metals that pose urgent health problems. As a recent authoritative study put it, "mercury is but one of approximately two dozen metals that are highly toxic to plants and animals". These metals "include lead, arsenic, cadmium, chromium, and nickel".[68] The horrors and pain of cadmium poisoning (bones become so brittle that a cough can shatter ribs) is such that a young Japanese girl worker committed suicide upon suspicion she was so poisoned.[69]

The treatment of DDT represents a fascinating case-study of the way people, industries, professions, and governments grapple with the two-sided products of science and technology. The late Rachel Carson, who wrote *Silent Spring* in 1962, was one of the first to raise doubts about the use of DDT. The book was branded by some as insupportable sensationalism,[70] but seven years later DDT had been banned or severely restricted in many developed countries, for example, Denmark, Sweden, and in some of the American States. It has also been restricted in Canada; measures introduced at the beginning of 1970 should reduce its use by 90 per cent.

DDT residues have been found in animals and humans in many parts of the world and some researchers have even intimated that there might be serious side-effects for human beings; for example, "Neurophysiologist Alan Steinbach of the University of California at Berkeley claims that DDT is an irreversible nerve poison".[71] Although there are many similar claims, the President of the American Association for the Advancement of Science, a noted biologist, said recently, "No human has yet been known to be damaged in consequence of normal usage of DDT. . . ".[72] Nevertheless, what must strike laymen as bizarre and unseemly is the fact that in many places it has been found that mother's milk contains more DDT or other pesticides such as dieldrin than the acceptable limit for commercially sold milk. In 1968, Göran Löfroth of the Institute of Biochemistry, University of Stockholm, wrote: "Many parents are faced by a difficult choice. Should they expose their child . . . to an unknown and high amount of organochlorine pesticides, or should they deprive the child of nutritious milk and warm contact with its mother?[73]" The Ehrlichs comment: "The continued release of chlorinated hydrocarbons into our environment is tantamount to a reckless global experiment, and we humans, as well as all other animals that live on this globe, are playing the role of guinea pigs."[74]

Here again we find evidence of the ambivalent nature of many current problems of science and technology. The dilemma Löfroth poses—between motherly warmth plus organochlorine pesticides and neither—is of a kind that is increasingly found hanging around the problems of pollution. How does one balance the short-term gain against the long-term loss, and vice versa? At first blush the question whether or not to use DDT, for instance, looks like a scientific question that can be given an unambiguous answer. But that turns out not to be so, or not always so. For those trained to look for short-term effects (e.g. classical toxicologists, food technologists, or agri-chemical engineers) might say "use it" where those professionally concerned with long-term effects (e.g. microbiologists and geneticists) might say "don't use it." This conflict of experts becomes more apparent when the long-term effects of low-level pollution are involved. The distinguished science policy commentator Alvin Weinberg has proposed the epithet *trans-scientific* for questions that "seemingly are part of science yet in fact transcend science—that is, are incapable of resolution by science".

"As scientists," Weinberg wrote recently, "we must admit that some questions, including the most important ones raised by concern for the environment, are really trans-scientific, not scientific." He went on to emphasize the ambivalent quality of many contemporary scientific questions:

> To decide on standards when science can say neither yea nor nay requires some procedure other than the one usually used by scientists in resolving bona fide scientific questions. Some version of the adversary procedure . . . is the best we now have for resolving the trans-scientific questions that underlie so many of the conflicts between science and technology, and society.[75]

If the adversary procedure offers a way of breaking through the dilemmas trans-scientific problems pose in society, then it certainly merits consideration.[76]

Many scientists predict that the effects of pollution will soon cause more than personal annoyance. By the year 2000 the carbon dioxide produced by burning fuels accumulating in the earth's atmosphere will, it is said, inhibit the escape of the earth's heat to a point where it will begin to melt the Antarctic ice cap. A report of the U.S. president's Science Advisory Committee commented on this:

> The melting of the Antarctic ice cap would raise sea level by 400 feet. If 1,000 years were required to melt the ice cap, the sea level would rise about 4 feet every 10 years, 40 feet per century.[77]

There is the suggestion that this might take place at twice the rate; at any rate, it would cause havoc in major sea-port cities.[78] However, another type

of pollution—increasing particles in the atmosphere—can cause the earth to cool by blocking off the sun's rays. Dr. Haagen-Smith of the California Institute of Technology, the Chairman of California's Air Resources Board, has said a smog pollution blanket could grow thick enough to block out the sun's rays,[79] leading to a large drop in temperature and a new ice age.[80] Skolnikoff quotes evidence of another possible source of cooling: on average about 31 per cent of the earth's surface is covered by low cloud, but increasing this to 36 per cent would drop the temperature about 4°C, a drop close to that required for a return to an ice age.[81] It would not be safe to assume that man will be able to adapt to these conditions. In any case, by then the ultimate disaster, the extinction of life on earth, might well have been brought about by depletion of the oxygen in the environment; in fact, this catastrophe could happen in the near future, according to the biologist Dr. LaMont Cole. The atmospheric oxygen we require for life is produced by green plants which take in the carbon dioxide produced by animals, micro-organisms, factories, furnaces, and automobiles. Seventy per cent of the free oxygen produced each year comes from phytoplankton in the oceans. If by careless pollution of the oceans men killed an appreciable amount of this plankton the oxygen balance could be fatally changed. The late Lloyd Berkner apparently has suggested that the ultimate disaster could occur if a very few *Torrey Canyons* carrying a concentrated herbicide broke up in the North Sea.[82] Yet according to the U.S. Food and Drug Administration, the oceans are even now receiving great quantities of pollutants, consisting of some half-million substances many of which are recently developed, biologically active materials to which the earth's living forms have never before been exposed.[83] Only a negligible fraction of these substances have been tested for toxicity to marine diatoms and Dr. Cole comments:[84] "I do not think we are in a position to assert that we are not poisoning the marine diatoms and thus bringing disaster upon ourselves."

Even if Cole is too gloomy on this point, he claims that carbon dioxide is being added to the atmosphere more rapidly than the oceans can assimilate it. Some assume that this might bring about a slow decrease of atmospheric oxygen, but Berkner did not share this optimism, claiming that the atmospheric depletion could occur suddenly and disastrously.[85] The same effect might also result from an increase in industrialization, according to Cole: "If we should seriously attempt to industrialize all the nations of the earth after our own pattern, I think we would all perish for lack of oxygen before the transition was nearly complete.[86]

It must be pointed out that there is controversy among scientists as to whether or not there is a potential man-caused danger to the earth's oxygen supply. Wallace S. Broecker claims that "If man's existence is to be threatened by pollution of the environment he will succumb to some other fate long before his oxygen supply is seriously depleted."[87] As eminent a scientist as Professor Jean Piccard recently warned that lead poisoning of plankton in the upper layers of the oceans might reduce the oxygen content of the atmosphere. Britain's magazine *New Scientist* noted that Piccard was quickly contradicted by "the doyen of organic chemists", Sir Robert Robinson, but that "Sir Robert (who is a consultant for Shell) was shot down by Dr. David George of the British Museum."[88] Such differences of opinion are matters on which parliaments and governments must take ultimate responsibility. The conflicts, and they are mainly between scientists, can only be resolved as public issues at the political level. Yet there are many other worries about lead aside from this one, and some scientists are already alarmed at the lead pollution of the environment and its intrusion into the human blood stream.[89] Parliaments will also have to contend with the sources of pollution; for example a considerable amount of environmental lead comes from leaded gasoline, but to produce lead-free gasoline in Canada will, according to H. R. Clare, environmental protection co-ordinator of Imperial Oil Limited, require a capital investment of "about $600 million for the Canadian petroleum refining industry". He added that the controversy over lead-free gasoline was "an almost classic example of the dilemma facing both government and business as a result of public pressures which are based more on emotion than on fact."[90] Governments clearly cannot ignore such situations.

Another threat to the environment stems from the waste produced by a high-consumption throw-away society. In North America the solid waste discarded each day has created a garbage business that grosses about $5 billion and is growing as fast as the computer industry.[91] There are estimates that by the mid-1970's North Americans will be spending ten per cent of the gross national product on solid waste disposal.[92] Recently in New York the cost of collecting and transporting one ton of waste was three times the cost of Virginia coal mined and delivered to New York.[93] Some idea of the magnitude of the problem can be gained from the calculation that North Americans throw away enough solid waste each year to build a wall 75 feet wide and 20 feet high along the Canada-U.S. border.[94]

It is not only domestic waste that must be dealt with. Industrial waste presents an even more complex problem because international product com-

petitiveness and jobs can be involved. For example "H. D. Paavila, manager of the Canadian Pulp and Paper Association's Environmental Service Office, estimated the capital cost of treatment facilities for liquid wastes from the mills at something between $650 million and $750 million".[95] Mr. Paavila went on to note that "In view of the depressed economic condition of the Canadian pulp and paper industry generally . . . a major undertaking for water pollution abatement over a short space of time would have disastrous effects on this industry".

The threat to the stability and livability of the human environment is man made. The United States, with a larger population, usually experiences environmental problems before Canada and can therefore serve as Canada's "early warning line". A mass circulation U.S. magazine recently noted that ". . . scientists have solid experimental and theoretical evidence to support each of the following predictions:

> In a decade, urban dwellers will have to wear gas masks to survive air pollution.
>
> In the early 1980's air pollution combined with a temperature inversion will kill thousands in some U.S. city.
>
> By 1985 air pollution will have reduced the amount of sunlight reaching earth by one half.
>
> In the 1980's a major ecological system—soil or water—will break down somewhere in the U.S. New diseases that humans cannot resist will reach plague proportions.
>
> Rising noise levels will cause more heart disease and hearing loss. Sonic booms from SSTs will damage children before birth.[96]

Some people think these threats to environmental ecology are pointed not only at human and social development but also at science itself. For example, a chemist has recently stated:

> . . . for at least the next decade, the most important, active, and heavily funded field of science will be ecology—in its broadest sense. Unless we reach a full and effective understanding of human society and its place in the biosphere, there will be no science worth speaking of in the 21st century.[97]

The writer goes on to state that although the younger generation is, as a group, deeply interested in all aspects of ecology, it will not give the required support for the scientific study of ecology—or anything else, presumably—until convinced that science is neither "irrelevant" nor even "demonic".

Probably overshadowing all other concerns are those of hunger and the possibility of global death by nuclear war.[98] Medical advances have helped prolong life[99] and reduce infant mortality, with a consequent increase in

population and human hunger. Nuclear energy, which promises to supply almost unlimited cheap power, also holds the possibility of reducing the green-blue globe to a lifeless cinder. But there are also doubts about the safety of "peaceful" nuclear power reactors.[100] Whether these published accounts are soberly authoritative or wildly alarmist, the public interest in the matter is obvious and legitimate. The situation in the United States is further confused by the fact that two scientists, John W. Gofman and Arthur R. Tamplin, have actively campaigned against the safety standards set by the U.S. AEC which, they claim, are too lax. Although the AEC contests the claims of Gofman and Tamplin, the public has every excuse for being concerned, for these are life scientists working in an AEC-funded laboratory on the possible effects of radiation on man.[101] The public would understandably feel further concern when it reads the verdict of the U.S. Court of Appeals for the District of Columbia; the court said that the U.S. Atomic Energy Commission's nuclear-plant licensing regulations had made a "mockery" of the 1969 U.S. National Environmental Policy Act.[102] The court told the AEC to revise its regulations to abide by the act's requirement that it consider the environment "to the fullest extent possible" at every stage of licensing.

This Committee is in no position to comment technically on Canada's nuclear safety standards. However, the task of the Atomic Energy Control Board is to check the activities of a few specific government agencies, and the Committee is startled to realize that most of the members of this controlling board prove to be senior representatives of these very government agencies rather than representatives of the public whose safety from radiation is obviously the important goal of the board's activities. The Committee does not suggest that Canadian standards are as a result deficient but does suggest that this administrative arrangement is inept from the point of view of the public interest. It is interesting to note that in the United Kingdom a new National Radiological Protection Board was set up under the Radiological Protection Act of 1970; the Board will include a wide range of professional people and representatives of the public. The *New Scientist* commented that it was necessary "to seek actively the fullest possible public participation in nuclear decisions and to consider seriously the objections of all responsible critics".[103]

As with the atom, so with the human cell: knowledge has brought awesome power.

Nobel prize winner James D. Watson warned an international conference of legislators that "Some people may very sincerely believe the world desperately needs many copies of the really exceptional people if we are to fight

our way out of the ever-increasing computer-mediated complexity that makes our individual brains so frequently inadequate."[104] Totalitarian states could thus make any number of "Xerox copies" of people whose prowess is considered of value to the state.

Watson further warned: "Clearly even more bizarre possibilities can be thought of, and so we might have expected that many biologists, particularly those whose work impinges upon this possibility, would seriously ponder its implications, and begin a dialogue which would educate the world's citizens and offer suggestions which our legislative bodies might consider in framing national science policies. On the whole, however, this is not at all what has happened."[105]

Watson goes on:

> . . . It appears to me most desirable that as many people as possible be informed about the new ways of human reproduction and their potential consequences, both good and bad. This is a matter far too important to be left solely in the hands of the scientific and medical communities. The belief that surrogate mothers and clonal babies are inevitable because science always moves forward . . . represents a form of laissez-faire nonsense . . . . I would thus hope that over the next decade wide-reaching discussion occurs, at the informal as well as formal legislative level, about the manyfold problems which are bound to arise if test tube conception becomes a common occurrence . . . . if we do not think about the matter now, the possibility of our having a free choice will one day suddenly be gone.[106]

Thus science, in breaking the atom and unlocking the secrets of human genetic material, has twice posed cardinal decisions upon mankind in this century. It is rare, however, for basic science itself to lead so quickly to potential threats to society. More commonly the threats to people arise from the applications of technology.

THE DILEMMAS OF SCIENCE AND TECHNOLOGY

Science and technology, then, have revolutionized the character of life in the developed countries and given their citizens degrees of comfort, ease, choice, and wealth available only to princes a few centuries ago; while at the same time they increasingly pose a terrible threat to the continuance of the affluent life they created—indeed even to all life on earth. As Gordon Rattray Taylor has put it: "The technological dream is becoming a nightmare and it is time to wake up, or we may die in our sleep."[107]

Many other well-placed writers have recently shown alarm over the dangers a rapidly growing technology presents to mankind. The Nobel physicist Max Born wrote in his Recollections:

> I am haunted by the idea that this break in human civilization, caused by the discovery of the scientific method, may be irreparable. Though I love science I have the feeling that it is so much against history and tradition that it cannot be absorbed. . . . Should the race not be extinguished by a nuclear war it will degenerate into a flock of stupid, dumb creatures under the tyranny of dictators who rule them with the help of electronic computers.[108]

More recently the psychoanalyst Erich Fromm wrote a book with the subtitle *Toward a Humanized Technology*. He described it as a book "born out of the conviction that we are at the crossroads: one road leads to a completely mechanized society with man as a helpless cog in the machine—if not to destruction by thermonuclear war; the other to a renaissance of humanism and hope—to a society that puts technique in the service of man's well-being".[109] Fromm begins with the words:

> A specter is stalking in our midst whom only a few see with clarity. It is not the old ghost of communism or fascism. It is a new specter: a completely mechanized society, devoted to maximal material output and consumption, directed by computers; and in this social process, man himself is being transformed into a part of the total machine, well fed and entertained, yet passive, unalive, and with little feeling.[110]

Fromm observes that one of "the technological society's pathogenic effects upon man"[111] is the disappearance of *privacy* (a second, he claims, is the disappearance of personal human contact). Some evidence that contemporary students are reacting against technology's threat to privacy was obtained in a recent poll of 2,000 U.S. college seniors: "the most distinctive and obvious trait" was the emergence of a new ideology called "privatism" by the investigator; it "acknowledges the privileges of private existence—as rights—to all men."[112]

If sentiments develop in Canada as they have in other countries, students might grow to consider research and development, and the educational training necessary for performing it, to be "irrelevant". For example, in the United Kingdom "in spite of lavish financial prospects, large numbers of exceptionally able young people resolutely declined to pursue an orthodox scientific career,"[113] and in the United States Harvey Brooks reported that "what is more disturbing is an apparent revulsion against science by the whole society, and especially among young people".[114] During the Senate Committee's visit to Europe observers in all countries told of students swinging away

from the physical sciences. These observers reported students leaving their degree courses in physical science because "the professors are not interested in anything but science and we will have to work in ivory towers insulated from the real world". The majority of the graduating class of one of Europe's most distinguished technological institutes said they would not take a degree in engineering if they were now entering university, because it did not lead to work which seemed relevant to what they regarded as the "real human problems".

Editorials and articles about student unrest in Europe claim that they oppose the technocracy of East and West alike, and are overwhelmed by technological developments which they do not understand.[115]

Little has been published on the attitudes of Canadian students[116] towards science but John Kettle has reported discussions with Toronto high school students that showed them to have a negative reaction to science.[117]

Not only students and young people are worried by the impact of science and technology; some national leaders are equally concerned. For example, the late U.S. President Dwight Eisenhower remarked that "science seems ready as a final gift to confer upon us the power to remove all human life from this planet".[118] And he also said:

> Yet, in holding scientific research and discovery in respect, as we should, we must also be alert to the equal and opposite danger that public policy could itself become the captive of a scientific-technological elite.[119]

Another American general, James M. Gavin, now chairman of the board of Arthur D. Little, Inc., in commenting on the scientific revolution, claimed that it "created a wide gap between the world as it is and the world as we believe it to be" and that this led to distortions of thinking which he believed resulted in the Vietnam war and the deterioration of U.S. cities.[120]

Many have noted the technological compulsion of modern man: the assumption that we want to do everything imaginable, indeed have a duty to do it, and only lack of technical ability is restraining us.

As one writer noted:

> . . . feasibility, which is a strategic concept, becomes elevated into a normative concept, with the result that whatever technological reality indicates we *can* do is taken as implying that we *must* do it.[121]

Erich Fromm argues that this is a guiding principle of contemporary technological society, with the result that "all other values are dethroned, and technological development becomes the foundation of ethics."[122]

There are many who agree with Fromm, who see society in the developed countries shaped and buffeted by the unrestricted imperatives of technology. They argue that the invisible hand posulated by the proponents of economic *laissez faire* is even less effective in protecting people from the ill effects of technological *laissez faire*.

The complex problems of technological fallout are ultimately the responsibilities of governments. Perhaps governments are no better equipped to solve the dilemmas than anyone else; but the citizens look to government for protection from this newest threat as they have looked to governments for protection from thieves and war, and in the Committee's view they have the right to ask for this protection.

TECHNOLOGY AND CANADIANS

In this discussion of the two faces of science and technology the focus has been on mankind as a whole, on the integrity of the globe. Although 98 per cent of the world's science and technology will be conducted outside Canada these activities will nevertheless constitute a potential threat to Canadian economic activity and development.

One vital area is the effect of new technology on jobs. The Economic Council of Canada warned that the growth in our labour force between 1965 and 1980 would exceed "by over half a million the labour force growth expected in Britain, West Germany and Italy put together and equals the entire existing Swedish labour force".[123] This is the kind of threat to employment inherent in new technology:

- Most of Canada's pulp and paper is exported; but what if low-cost, high-quality synthetic paper is developed?
- Will newly developed materials or worries about pollution weaken the demand for our exports of such primary products as asbestos or lead?
- Will new methods of locating mineral ores and refining and processing them cause shutdowns in our mining and refining industry?
- Will new discoveries in agriculture, the new food analogues or the synthetic production of protein, result in reduced wheat exports?
- What effects will improving methods of fishing as well as fish farming or mariculture have on Canadian maritime employment?
- The major powers are rapidly developing technology to exploit the continental shelves as well as the ocean floor itself. As a maritime nation what will Canada's response be and what effect will a global exploitation of the oceans have on Canadian development?

These are just a few of the possibilities that spring to mind.

The Canadian quality of life can also be affected by global technology. For example new means of weather control, satellite surveillance, or broadcasting can all permit one nation to intrude on another. Pollution from one country can step over into another; if increasing atmospheric dust leads to a new ice age Canada will be first in line to experience this result of global carelessness.

Technological advance can affect the relations between Canada and its neighbours. For example there are international questions of permafrost, fresh water resources, energy resources, ecology and the preservation of various species, compatible communication systems, river flow diversions, and recreational land use, to name just some questions involving technology. Technology has now become an important concern of diplomacy.

As technology affords new and better opportunities Canadians will rightly question any lag in receiving the advantages, too. For example, could infant mortality be reduced by methods pioneered in other countries? Are Canadians benefiting from the new housing technology developed in Europe and the United States? What about the educational advantages promised by new communications technology? Or the opportunities offered by the world's growing transportation technology? It will be important to know what others are doing and to judge whether the advances can be usefully employed here too.

TECHNOLOGY, ECONOMIC GROWTH, AND THE QUANDARY OF MANKIND

In the face of what Nigel Calder calls the "standard horrors" of today's technology, there is serious danger that it might be getting out of control. Elmer Engstrom, the president of Radio Corporation of America, said in 1967:

> The introduction of new technology without regard to *all* of the possible effects can amount to setting a time bomb that will explode in the face of society anywhere from a month to a generation in the future.[124]

In the so-called advanced world, man the discoverer, creator, and entrepreneur has shown almost unlimited capabilities. In spite of the warning given to us by Malthus, we believed until recently that our creative genius could liberate us from the limitations of nature. As the first industrial revolution emerged, man opened the era of fabulous technology. His control over nature seemed overwhelming and his ability to use it for his own

unlimited aspirations appeared to be infinite. Indeed his creativity coupled with his entrepreneurial spirit increased nature's potential substantially and led to the belief that unlimited growth was possible. Science became "the endless frontier" and collective affluence, this old dream of mankind, became a reality, at least in large parts of the western world.

It is becoming apparent, however, that nature is not as passive as we thought, that it has its own laws and can revenge itself, once its own equilibrium has been disrupted. We find that technology can have negative side-effects on man and his environment far exceeding its beneficial contribution. We are also discovering that nature may have a long memory: thus experts are now asserting that "even a total ban on the use of DDT [imposed today would leave] society exposed to high levels of DDT contamination for 30 years."[125] Nature imposes definite constraints on technology itself and if man persists in ignoring them the net effect of his action in the long run can be to reduce rather than increase nature's potential as a provider of resources and habitable space.

But then an obvious question arises: How can we stop man's creativeness? How can we proclaim a moratorium on technology? It is impossible to destroy existing knowledge; impossible to paralyze man's inborn desire to learn, to invent, and to innovate.

In the final analysis we find that technology is merely a tool created by man in pursuit of his infinite aspirations and is not the significant element invading the natural environment. It is material growth itself that is the source of conflict between man and nature. In the developed countries, in spite of rising affluence, we are still collectively seeking more growth. As René Dubos says: "We dislike polluted and cluttered environments, but we like economic prosperity and gadgets even more."[126] The average man used to believe that affluence would bring him happiness. And he still believes it, in spite of the mounting problems of affluent societies and of the fact that his rising affluence tends to multiply rather than to reduce his wants and aspirations. But as the increase in his income is accompanied by chronic inflation, it is not sufficient to enable him to satisfy all his new desires. Thus he is more frustrated and revolted than when he was really poor. Even that, however, does not cause him to call a halt; rather, it leads him to demand an ever greater economic growth that can only be obtained by increasing the flow of innovations and by a more dangerous exploitation of nature's limited non-renewable resources and habitable space. Thus advanced countries seem to have fallen into a vicious circle, affluence generating the endless need for further affluence. In material terms they appear to be condemned to grow

exponentially. The new demand for the good life may simply be added to the old aspiration for the "goods life". Thus, the advanced countries produce an economic growth explosion or, more precisely, an endless growth spiral. This concentration on growth has moved Dennis Gabor to declare in his recent book *Innovations*: "Unfortunately all our drive and optimism are bound up with continuous growth; 'growth addiction' is the unwritten and unconfessed religion of our times . . . . History must stop, the insane quantitative growth must stop."[127] Serious as it is, the growth spiral would not be catastrophic if it were the only one operating because, according to recent projections, the advanced countries will constitute less than 20 per cent of the world population in the year 2000.[128] We are becoming aware, however, of another frightening phenomenon. In the developing countries, a quite different growth model is at work. As they go from the stage of misery to that of poverty, they experience a population explosion produced by more food and better medical care and manifesting itself in a growing life expectancy for women and lower infant mortality. This creates another vicious spiral by delaying the increase in living standards that seems to be the only "natural" condition guaranteeing a substantial decline in the birth rate. Recent projections, which include sustained external aid, show that if current trends continue, annual income in most developing countries will not reach $300 per capita before the 22nd century, a level that was passed in Canada more than 100 years ago. Moreover, the Green Revolution is more likely to produce rising unemployment in the cities than to stop the population explosion.

Thus the developing nations, like the advanced countries, seem to be condemned to an exponential law of growth, although in their case the explosion will be demographic rather than economic. The two patterns will have a similar negative impact on the natural environment, though. Dr. Lester R. Brown said about the Green Revolution: "The central question is no longer 'Can we produce enough food?' but 'What are the environmental consequences of attempting to do so?' "[129] Moreover, the two growth models will also produce a rapidly widening affluence gap between the two worlds.

There, then, lie two dimensions of the quandary of mankind. First, a growing number of experts express the view that the system relating man to nature is reaching a breaking point. For instance Norbert Wiener was already warning us in 1962:

> There is a real possibility that changes in our environment have exceeded our capacity to adapt. The real dangers at the present time—the danger of

> thermonuclear war, the computing-machine sort of danger, the population-explosion danger, the danger of the improvement of medicine (to the extent that we shall very soon have to face not letting people live as part of the policy of letting them live)—all of these dangers make one wonder whether we have not changed the environment beyond our capacity to adjust to it, and whether we may not be biologically on the way out.[130]

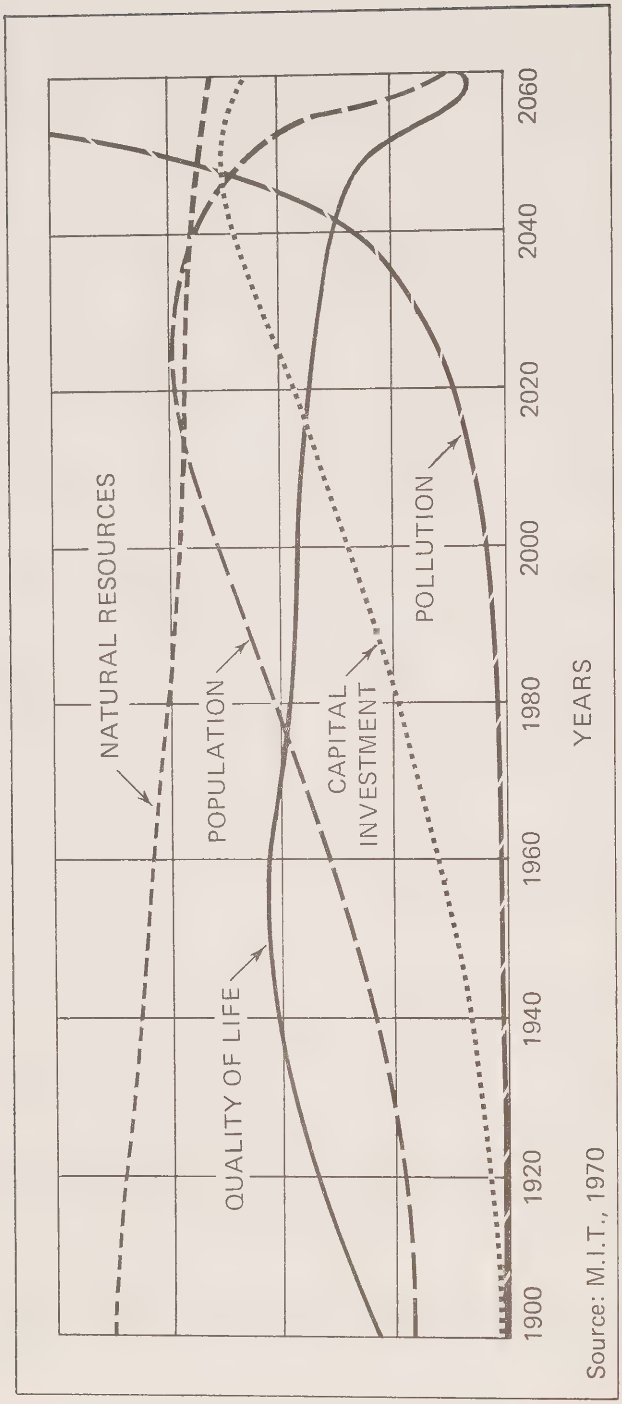
Opinions about the timing of the breaking point vary. According to a model built by the System Dynamics Group of MIT for the consideration of the Club of Rome, the material standard of living of the world will peak toward the end of the present century; during the first quarter of the 21st century per-capita food supplies will begin to decline, the death rate will start to rise, and eventually world population will take a downward turn. This model assumes, of course, a surprise-free scenario, with no thermonuclear war or radical change in man's life pattern. The MIT group's projections were summarized in the form of a computer-printed graph, which we reproduce here.

Yet the exact timing of these events is not really important. What matters is that in the absence of some radical change in conditions the system relating man to nature will break down sooner or later and in the process either the natural environment and mankind may be destroyed or a new equilibrium will be established by stopping the two growth spirals. Thus the question: How can the collision between nature and mankind be stopped?

The second aspect of mankind's quandary is the widening gap between the rich and the poor worlds. According to Lester Brown, in 1965 the standard of living in the United States, expressed in terms of annual per-capita income, was 47 times as high as India's. But in 1995 it is expected to be 115 times as high.[131]

It would be surprising, however, if world evolution were allowed to follow this course indefinitely. The poor countries will not tolerate this rapidly widening gap between the two worlds forever, especially as the new means of communications will directly expose an immense army of poor people to knowledge of the growing wealth enjoyed by that rich 20 per cent of the world's population. But then the question arises: How can this widening gap be reduced significantly during the next thirty years? Most commentators agree with René Dubos when he recently commented:

> Whether we want it or not . . . we shall soon be compelled to reformulate the philosophy of quantitative growth which has governed the Western world since the Industrial Revolution.[132]



RESOURCE DEPLETION HALTS GROWTH

CONCLUSION

The dark side of technology, the impending breakdown in man's relation to nature, and the affluence gap are three major problems of which we are forewarned by current trends and projections. We do well to pay serious attention to these warning notes. Fortunately, as René Dubos says, "Trend is not destiny".[133] A country like Canada, particularly, ought not to become over-pessimistic simply because global trends seem to point in a dangerous direction. We cannot panic, jettison science and technology, and deny ourselves a share of the benefits that they produce. But we can no longer continue to play the part of Scorerer's Apprentices, or nature will begin to stop the flood in its own way.

More specifically, we must learn how to derive the maximum benefits from science and technology and how to protect ourselves not only from their own negative side-effects but also from the negative impact of material growth itself. We must also find ways of growing in terms other than material and to increase our happiness without destroying our natural environment. The future need for innovation is described by Dennis Gabor in his book *Innovations* as: "Innovation must not stop—it must taken an entirely new direction. Instead of working blindly towards things bigger and better, it must work towards improving the quality of life rather than increasing its quantity. Innovation must work towards a new harmony, a new equilibrium; otherwise it will only lead to an explosion".[134]

We must learn to design and manage the public institutions associated with science and technology more effectively; we must overcome the time lags and inertia that characterize almost all institutions, these factors that conspire to deflect institutional concern from the problems of today and tomorrow to problems that are already embalmed by history.

In other words, if we do not want the trends to become our destiny we must "invent our future".[135] An overall coherent science policy can make a vital contribution to the greatest challenge that mankind has yet had to face in its long history. The Committee shares the view of a growing number of experts that there is not much time to launch this unprecedented operation; if the new strategies and institutions it requires are not forged within the 1970's, at the national and global levels, our planetary problems will have become so staggering as to be beyond control. The short-term difficulties should not prevent us from declaring a state of world emergency and taking action now to deal with our long term future.

NOTES AND REFERENCES

1. Marie Boas, *The Scientific Renaissance*, 1450-1630, Harper and Bros., New York, 1962.
2. Herbert Butterfield, *The Origins of Modern Science*, revised edition, The Free Press, New York, (paperback edition, 1965), p. 7.
3. René Dubos, *The Dreams of Reason, Science and Utopias,* Columbia University Press, New York, 1961 (Columbus paperback edition, 1963), p. 22.
4. Robert Merton, *Science, Technology and Society in Seventeenth Century England,* Bruges, 1938, Chap. 15.
5. Descartes, *Discourse on Method,* Pt. 6, quoted by John Herman Randall *The Making of the Modern Mind,* third edition, Houghton Mifflin, Boston, 1940, p. 224.
6. This growth has been perceptively charted by Derek J. de Solla Price in his books *Science Since Babylon,* Yale U.P., 1961, and *Little Science, Big Science,* Columbia U.P., 1963.
7. Michael D. Reagan, *Science and the Federal Patron,* Oxford U.P., New York, 1969, pp. 11-12.
8. OECD Document SP 71(10), p. 5. *R&D in OECD Member Countries: Trends and Objectives.*
9. Michael Harrington, *The Accidental Century,* Penguin Books, Baltimore, Maryland, 1966, p. 242.
10. *Quotations from Chairman Mao Tse-Tung,* Foreign Languages Press, Peking, 1966, pp. 204-205. (The statement was made in 1940.)
11. Based on *total* gross national product. A British journalist's account is by P. B. Stone, *Japan Surges Ahead: Japan's Economic Rebirth,* Weidenfeld & Nicholson, London, 1969. An experienced French observer's account is that by Robert Guillain, *The Japanese Challenge: The Race to the Year 2000,* J. B. Lippincott, New York 1970. (original edition *Japon, Troisième Grand,* Les Éditions du Seuil, Paris, 1969). Herman Kahn has written the speculative *The Emerging Japanese Superstate, Challenge and Response,* Prentice Hall, Englewood Cliffs, N.J., 1970.
12. Thomas S. Kuhn, "The Relations Between History and History of Science", *Daedalus,* Spring 1971, p. 285.
13. Ibid, p. 283.
14. The Senate Special Committee on Science Policy, *A Science Policy for Canada; A Critical Review: Past and Present,* Ottawa, Vol. 1, 1970, p. 3.
15. Walter Orr Roberts, *American Scientist,* 1967, quoted by René Dubos, *Reason Awake,* Columbia University Press, New York, 1970, p. 64.
16. It is estimated that the Black Death of the 14th century, bubonic plague, killed 25 million Europeans, in some countries a third of the populace; and the Great Plague in London in 1664-1665 killed a sixth of the entire population. *Technology Review,* May, 1968, pp. 35-36.
17. René Dubos, *Man Adapting,* Yale University Press, 1965, pp. 163 and 369.
18. Harold M. Schmeck Jr., "In Health, the Accent Switches to Prevention", *New York Times,* January 12, 1970, p. 75.
19. Dr. Howard A. Rusk M.D. points out (*The New York Times,* Sunday, December 13, 1970) that the rubella epidemic in 1964 was responsible for the death and disability of many thousands of infants. The cost of hospitalization, medical care, rehabilitation and special education for the multihandicapped survivors in the U.S. has been estimated to have exceeded \$2 billion. Rubella epidemics, he claims, occur in North America in six to nine year cycles.

    The U.S. government, for example, set the objective of immunizing 60 million pre-adolescent children by mid-1975 to hopefully avoid a repeat of 1964-65 when 20,000 babies were born with serious birth defects and an additional 30,000 pregnancies ended in spontaneous abortions and stillbirths. ("Rubella Vaccine Sped to Millions", *New York Times,* 22 March 1970). Nevertheless, Jane Brady ("New Research on Rubella Challenges Effectiveness of Vaccination Program", *New York Times,* 29 September 1970) reported that there was some evidence that the vaccine does not produce as strong immunity to rubella virus as does natural infection. It is also claimed that a small per-

centage of vaccinated children can serve as carriers of the disease (article by Walter Sullivan, *New York Times,* 4 August 1970).

20. Dr. Ralph E. Johnson of the U.S. National Cancer Institute. Quoted in *Newsweek,* 22 February 1971, p. 90.
21. *Newsweek, op. cit.,* pp. 88 and 90. Also *The Globe and Mail,* 28 January, 1970.
22. Spun soybean fibres prepared to taste like real meats are being test-marketed in several northeastern states of the U.S.A., often without the consumer's knowledge; dozens of hospitals, prisons, public restaurants, schools and industrial cafeterias are using such "meat analogues" in their daily menus. It is estimated that in 10 years' time imitation meat will be a $2 billion industry in the U.S. (Sandra Blakeslee, High-Protein Food, Created in Laboratories, Is Starting to Enter the Consumer's Diet, *New York Times,* March 1, 1970.)
23. "Japanese to Produce Meat from Wheat", *New York Times,* 29 November, 1968.
24. Jean Mayer, "Toward a Non-Malthusian Population Policy", *Columbia Forum,* Summer 1969, Volume XII, No. 2, p. 5.
25. Sandra Blakeslee, *New York Times, op. cit.*
26. Magnus Pyke, "A Taste of Things to Come", *New Scientist,* 17 December 1970, pp. 512-514. See also John Murray, *Synthetic Foods,* London, 1971.
27. Victor Basiuk, "The Impact of Technology in the Next Decades", *Orbis,* Spring 1970, p. 26.
28. J. C. R. Licklider, "Televistas: Looking Ahead Through Side Windows", appendix to *Public Television, A Program for Action,* the report of the Carnegie Commission on Educational Television, Bantam Books, New York, 1967, p. 211.
29. Albert G. Hill, Technology and Television, appendix to *Public Television, A Program for Action,* op. cit., p. 197.
30. A staff of 150 produce four basic first-year courses while 250 local offices supply staff offering tutorial assistance and career counsel and organizing opportunities for students to meet. Cost per student for one year is about $250 and a college degree can be obtained in three years. The facilities for the BBC Open University are about $10 million while about $20 million are spent as operating costs. *Business Week,* Jan. 16, 1971, p. 79.
31. For example, Richard M. Cyert, Dean of Carnegie-Mellon University Graduate School of Industrial Administration, envisions audio-visual centres and computer tie-ups around the country to transmit his school's new learning material. *Business Week,* December 5, 1970, p. 58.
32. *L'Express,* No. 1009, 9 to 15 Nov. 1970, p. 34.
33. Patrick Suppes, "The Uses of Computers in Education", *Scientific American,* Sept. 1966, (quoted by Charles E. Silberman, *Crisis in the Classroom: The Remaking of American Education,* Random House, New York, p. 187)
34. Patrick Suppes, *New York Times Annual Education Review,* Jan. 12, 1970, (quoted by Silberman, *op. cit.,* p. 188).
35. Anthony G. Oettinger, *Run, Computer, Run: The Mythology of Educational Innovation,* Harvard University Press, Cambridge, 1969, p. 215.
36. Victor Basiuk, "The Impact of Technology in the Next Decades", *Orbis,* Spring 1970, p. 26.
37. J. C. Thompson, "The Value of Weather Forecasts", *Science Journal,* Dec. 1969, pp. 62-67.
38. "The ERTS program and Canada", *Globe and Mail,* March 4, 1971.
39. R. P. Hammond, "Low Cost Energy: A New Dimension", *Science Journal,* January, 1969, pp. 34-44. Hammond claims that breeder reactors will eventually produce from granites containing only 12 ppm of uranium and thorium ten times as much energy as could be produced from an amount of coal of equal weight to the granite.
40. The U.S. AEC, the U.S. nuclear industry, and the U.S. electric utilities have mounted a large-scale effort to develop the breeder reactor to generate electricity on a commercial scale by 1984. Glenn T. Seaborg and Justin L. Bloom, "Fast Breeder Reactors", *Scientific American,* Vol. 223, No. 5, Nov. 1970, pp. 13-21.
41. Dr. I. N. Golovin, quoted in *Science Journal,* Dec. 1969, p. 17.

42. William C. Gough and Bernard J. Eastland, "The Prospects of Fusion Power", *Scientific American,* Vol. 224, No. 2, Feb. 1971, p. 64.
43. Arthur Galston, "Crops without Chemicals", *New Scientist,* 3 June 1971, pp. 577-579.
44. Pierre Teilhard de Chardin, *The Phenomenon of Man,* Collins, London, 1959, p. 250.
45. Quoted in "Man into Superman: The Promise and Peril of the New Genetics", Special Section, *Time,* 19 April, 1971, p. 35.
46. Some of the possibilities offered by the new biology are described by science journalist G. Rattray Taylor in *The Biological Time Bomb,* Thames and Hudson, London, 1968.
47. Paul Armer, "Computer aspects of technological change, automation, and economic progress", from *Technology and the American Economy,* the report of the National Commission on Technology, Automation, and Economic Progress, Appendix to Vol. 1, *The Outlook for Technological Change and Employment,* U.S. Government Printing Office, Washington, D.C., February, 1966, pp. 1-205 through 1-232.
48. John S. Saloma, "System Politics: the Presidency and Congress in the future", *Technology Review,* Dec. 1968, pp. 23-33. Expanded in book, *Congress and the New Politics,* Little, Brown and Company, Boston.
49. Already in West Germany Dr. Helmut Krauch has demonstrated that TV and computers can be used to allow "people—on a massive scale—to participate directly in political decision making". See "You too can govern the nation's future", *The Sunday Times,* London, July 18, 1971.
50. Olaf Helmer, "Science", *Science Journal,* October 1967, p. 50.
51. For example, F. G. Heath reviewed new developments in electronic circuitry in the February, 1970 issue of *Scientific American* ("Large-Scale Integration in Electronics"), pp. 22-31. He reported that the technology that produces circuits with a high density of circuit elements per unit area (LSI or large-scale integration) appears capable of laying down 50,000 to 100,000 components per square inch and commented that "If the upper value [100,000] could be achieved throughout a cubic inch of material (which may be done in another decade or so), the density of electronic components would be about a fourth the density of nerve cells in the human brain." Heath concluded: "Such is the potential for many new developments made possible by LSI: wristwatch television, robot toys a few inches high, a computer terminal for every home, electronically guided automobiles. One can predict that new markets of this kind will lead to a drastic reduction in the cost of LSI circuitry. The decade of the 1970's should be a boom time for microelectronics."
52. Quoted by Michael Harrington, (*The Accidental Century,* Penguin Books, Baltimore, 1966, p. 241), who considers the social implications of automation.
53. Olaf Helmer, *Social Technology,* Basic Books, New York, 1966, or: issue of *Science Journal* on forecasting the future, London, October 1967, Vol. 3, No. 10.
54. Harvey Brooks, "The Practical Uses of Pure Research", *New York Times,* January 12, 1970.
55. "Fighting to Save the Earth from Man", *Time,* Feb. 2, 1970, pp. 42-44.
56. René Dubos, "The Predicament of Man", *Science Policy News,* Vol. 2, No. 6, May 1971, p. 65.
57. John Cornwell, "Is the Mediterranean Dying?" *The New York Times Magazine,* Feb. 21, 1971.
58. Thor Heyerdahl, "The Voyage of the Ra II", *National Geographic,* January 1971, p. 55.
59. Editorial, "Man the Polluter", *New York Times,* July 23, 1969.
60. Debates of the Senate, Official Report (Hansard), October 23, 1969.
61. "Spills of Alaskan crude [oil] could shatter Arctic ecology", *New Scientist,* 24 December 1970, p. 538.
62. Philip Winslow, "Fabled St. Lawrence River 'an open sewer'", *Montreal Star,* Saturday, September 27, 1969.
63. Cited by Nigel Calder, *Technopolis, Social Control of the Uses of Science,* MacGibbon and Kee, London, 1969, p. 182.
64. "Mercury-treated seed poisons partridge, Alberta bans hunting", *Globe and Mail,* October 30, 1969.

65. On Feb. 22, 1970, the CTV television program "W5" presented a discussion on the use of methyl mercury seed dressing, and the effect of this compound in people as well as birds was graphically demonstrated. It was claimed that the mercury content of some Alberta pheasants and grouse was about five times the allowable level. A spokesman claimed that the Alberta government did not know methyl mercury was so dangerous, however, a Swedish pollution expert has told this Committee that methyl mercury is a "particularly vile compound". A university researcher stated on the TV program that Sweden banned the use of methyl mercury four years ago and commented: "What is missing in Canada is a mechanism to close the gap and to put knowledge into action."

66. Peter and Katherine Montague, "Mercury: How Much Are We Eating?", *Saturday Review,* Feb. 6, 1971, pp. 50-54.

67. This figure of 100 might appear to be too large to those reading the proceedings of the symposium sponsored by the Royal Society of Canada in February 1971 on the subject *Mercury in Man's Environment.* The introductory speaker at the latter symposium was AECL's W. E. Lewis who gave a historical introduction on mercury hazards in which he infers that 52 Japanese patients have been treated for Minemata disease and that ⅓ had died. Dr. Lewis also referred to "some of to-day's alarmist writers on pollution . . . "

 A conference of world experts on environment was called together at MIT and in their proceedings *Man's Impact on the Global Environment* (report of the study on critical environment problems, MIT Press, 1970) it is stated on page 137 "in Japan, 111 cases of mercury poisoning occurred (with 41 deaths) as a result of eating fish or shell fish taken from Minemata Bay . . . another outbreak occurred in Niigata City with 26 cases (and 5 deaths) due to the same cause.

68. *Man's Impact on the Global Environment: Assessment and Recommendations for Action,* Report of the Study of Critical Environmental Problems (SCEP), sponsored by M.I.T., The M.I.T. Press, 1970, p. 138.

69. The incidence of ouch-ouch disease (itai itai byo, or "it hurts! it hurts!") in a Japanese village is ascribed to the rice and soya beans grown locally and irrigated by waters contaminated by cadmium run-off from waste piles of a heavy-metal mine and factory nearby. Many other research results show strong correlations between lung, heart, liver and kidney diseases and exposure to cadmium, either through inhalation or oral ingestion. Nevertheless, some scientists and food and drug authorities, including Canadians, remain skeptical while, according to concerned researchers, safety levels are either non-existent or are set too high for long-term safety of populations. This is the sort of environmental problem characterized by conflicts of expert opinion, the resulting ambiguity of which causes understandable concern among public and parliamentarians alike. (See for example, Robert Nilsson, *Aspects on the Toxicity of Cadmium and its Compounds,* Ecological Research Committee, Bulletin No. 7, Swedish Natural Science Council, March 1970; Julian McCaull, "Building a Shorter Life", *Environment,* September 1971; Jon Tinker, "Ouchi-Ouchi: your cadmium's showing", *New Scientist and Science Journal,* 22 April 1971; "Metals Focus Shifts to Cadmium", *Environmental Science,* September 1971.)

70. It is claimed that *Time* denounced Rachel Carson's book as an "emotional and inaccurate outburst" and accused her of "putting literary skill second to the task of frightening and arousing readers" (*New York Times,* March 1, 1970, review of Frank Graham Jr.'s *Since Silent Spring*). René Dubos states that, following publication of Rachel Carson's book, President Kennedy appointed a committee of well-known experts to advise him on pesticides. Dubos claims the experts concluded that what Rachel Carson said was right and that further scientific study of the biological effects of pesticides was needed, "but", Dubos goes on, "I am absolutely sure that if any of the graduate students of these distinguished professors in these famous universities had wanted to work on pesticides, those students would have been invited to move somewhere else. I do know that none of the members of that Committee has done anything in the past seven or eight years to foster the development of studies on pesticide toxicity." (René Dubos, "We Can't Buy Ourselves Out", *Psychology Today,* March 1970, p. 22 and p. 86).

71. Paul R. and Anne H. Ehrlich, *Population Resources Environments: Issues in Human Ecology*, W. H. Freeman and Company, San Francisco, 1970, p. 132.
72. Philip Handler, "The Federal Government and the Scientific Community", *Science*, Vol. 171, No. 3967, 15 Jan. 1971, p. 148.
73. Göran Löfroth, quoted by Ehrlichs, *op. cit.*, p. 134.
74. Ehrlichs, *op. cit.* p. 134.
75. Alvin M. Weinberg, Letter to *Science*, November 5, 1971, pp. 546-547.
76. An example illustrating how this procedure is beginning to take hold is given by the U.S. Environmental Protection Agency Administrator W. D. R. Ruckelshaus, who in September 1971 stated: "Decisions such as the fate of DDT are not decisions solely within the purview of the scientist to make in his laboratory. Rather societal decisions about what kind of a life people want and about what risks they are willing to accept to achieve it." He went on to discuss in the following passage his own conception of the accountability of himself and of scientists to the public: "First, I am convinced that if a decision regarding the use of a particular chemical is to have credibility with the public, and with the media who may strongly influence that public judgment, then the decision must be made in the full glare of the public limelight. It no longer suffices for me to call a group of scientists to my office and, when we have finished, to announce that based on their advice I have arrived at a certain decision. Rather, it is necessary for me to lay my scientific evidence and advice on the table where it may be examined and, indeed, cross-examined by other scientists and the public alike before I make a final decision. I fully realize that my announcements calling a public hearing on the fate of DDT and making the scientific advisory committee report public in the case of 2,4,5-T and then calling a subsequent public hearing has concerned some scientists. I fully understand the scientist's desire to seek a quiet spot to contemplate and carefully work out rational solutions, as well as his distaste of the hysteria that sometimes accompanies public discussion of environmental issues. However, the demands of a free and open society will not permit such a luxury. My obligation is to make a public accounting of my decision—to explain why I have taken or refused to take certain action. You, too, must participate in this explanatory process, if it is to be successful. Regardless of whether those who support the decision speak out, some of the opposition to the action will be heard. And, all sides must be heard. Regardless of the emotion surrounding an issue, reason must prevail. To fail to publicly support a wise decision may well be to concede defeat in the battle to convince the public of the credibility of the decision, and without such credibility, neither you nor I will long be entrusted with decisions that the public considers vital to their lives."
77. *Restoring the Quality of Our Environment*, Washington, D.C. Government Printing Office, November 1965, p. 123.
78. Specialists can only crudely calculate what future increases in atmospheric CO_2 might be. One study indicates that it might increase by 20 per cent by the year 2000 and cause an increase of earth surface temperature of 1°C; it might even be more. What specialists agree upon is the need for a better understanding. See *Man's Impact on the Global Environment, Assessment and Recommendations for Action, op. cit.* pp. 55 and 88.
79. "Chemist predicts pollution may bring on new ice age", *New York Times*, August 9, 1969.
80. If the dust or particulates floating in the upper atmosphere increase, most of the sun's energy will be reflected, causing a drop in the temperature of the atmosphere. Some critics of the supersonic transport aircraft claim that the water vapour they will discharge into the upper atmosphere will increase the earth's cloud cover, further shielding the earth from the sun's energy. More recent calculation indicates that although there is little danger from the "greenhouse effect" of increasing CO_2 in the atmosphere, there may be a real danger from an increase in particulates in the atmosphere; an increase in opacity of a factor of 4 might be sufficient, if maintained over a period of a few years, to bring on another ice age. See S. I. Rasool and S. H. Schneider, "Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate", *Science*, Vol. 173, No. 3992, 9 July 1971, pp. 138-141.

81. Eugene B. Skolnikoff, *The International Functional Implications of Future Technology,* paper presented at The American Political Science Association Meeting, Los Angeles, September 1970.
82. LaMont C. Cole, *Can the World be Saved?* paper presented at the 134th meeting of the American Association for the Advancement of Science, Dec. 27, 1967, pp. 8-9; published in *Bio Science,* July, 1968.
83. *A Strategy for a Livable Environment,* U.S. Department of Health Education and Welfare, Govt. Printing Office, Washington, 1967, pp. ix, 5.
84. Cole, *op. cit.*, p. 9.
85. L. U. Berkner, *Population Bulletin,* 22, 83 (1966).
86. *Can Man Survive Pollution?,* Symposium, Georgia Tech., May 8, 1968.
87. Wallace S. Broecker, "Man's Oxygen Reserves", *Science,* 26 June 1970, p. 1538.
88. "A Lethal Element", *New Scientist,* 18 Feb. 1971, p. 340.
89. Ibid, p. 340. Recent evidence indicates that animals are the first to suffer from environmental lead. For example a large proportion of the animals in the Staten Island Zoo suffer from lead poisoning; see R. J. Bazell, "Lead Poisoning: Zoo Animals May be the First Victims", *Science,* Vol. 173, No. 3992, 9 July 1971.
90. Quoted in "Capital outlay for lead-free gas set at $600 million by refiner", *The Globe and Mail,* 23 Feb. 1971, p. B5.
91. *Cash is Trash? Maybe,* Forbes, Feb. 15, 1970, pp. 18-24.
92. J. Lukasiewicz, *Complexity and Saturation in an Environment of High Technology,* College of Engineering, Virginia Polytechnic Institute and State University, Report VP1-E-70-21, December 1970, p. 17.
93. Michael B. Walsh, "The Garbage Crisis: 'What can we do with it?' ", *The Ottawa Journal,* Dec. 2, 1968.
94. Assuming about five pounds of solid waste per person per day and a density of thirteen pounds per cubic foot.
95. "Pulp pollution curbs may be 'disastrous' ", *The Globe and Mail,* 23 Feb. 1971, p. 5.
96. "Ecology: a cause becomes a mass movement", *Life,* Jan. 30, 1970, p. 22.
97. Thomas R. Blackburn, "Sensuous—Intellectual Complementarity in Science", *Science,* 4 June 1971, pp. 1006-1007.
98. See, for example, *Unless Peace Comes, A Scientific Forecast of New Weapons,* edited by Nigel Calder, Viking Press, New York, 1968.
99. Dr. Leon R. Kass of the U.S. National Academy of Sciences predicts that "by the end of the century the 'useful' life span of some individuals may be extended 20 to 40 years". (Quoted in "Scientist Foresees a Longer Life Span, Mainly for the Affluent", *New York Times,* 23 Feb. 1971).
100. Sheldon Norick, *The Careless Atom,* Houghton & Mifflin, Boston 1969 and Richard Curtis and Elizabeth Hogan, *Perils of the Peaceful Atom,* Doubleday, N.Y., 1969. The much publicized critics of nuclear power, John W. Gofman and Arthur R. Tamplin have recently added their book to the nuclear power plant safety debate: *Poisoned Power,* Rodale Press, Emmaus, Pa., 1971. These authors state: "We are convinced, on the basis of our research, that radiation to be expected from the rapidly-burgeoning atomic energy programs is a far more serious hazard than previously thought possible." (Quoted in *The New York Times Book Review,* August 8, 1971, p. 21.).
101. This controversial and highly technical question is reviewed in *Science* for 6 Feb. 1970. The charges that Gofman and Tamplin have been "harassed" by the AEC are discussed in *Science* for 28 Aug. 1970.
102. "Nuclear Power Loses a Battle in Court", *Business Week,* July 31, 1971, p. 24.
103. "Nuclear Hazards and the Public", *New Scientist,* 7 Jan. 1971, p. 4.
104. James D. Watson, "Potential Consequences of Experimentation with Human Eggs", *International Science Policy,* Committee on Science and Astronautics, U.S. House of Representatives, Washington, 1971, p. 157.
105. Ibid, p. 151.
106. Ibid, pp. 159-160.
107. Gordon Rattray Taylor, *The Doomsday Book,* Thames and Hudson, London, 1970.

108. "Recollections of Max Born", *Bulletin of the Atomic Scientists,* September-November, 1965, (November issue, p. 6).
109. Erich Fromm, *The Revolution of Hope: toward a humanized technology,* Harper and Row, New York, 1968, (also in Bantam Book paperback), p. xvii.
110. Ibid, p. 1.
111. Ibid, p. 45.
112. Dr. Jeffrey K. Hadden, "The Private Generation", *Psychology Today,* October 1969 [noted in *New York Times,* Sept. 29, 1969.]
113. "Young People appalled by Science", *Manchester Guardian,* Dec. 21, 1967, quoted also by Harvey Brooks, "Physics and the Polity", *Science,* 26 April, 1968, p. 397.
114. "Physics and the Polity", *op. cit.,* p. 397.
115. "Soviets on the Campus", London *Observer,* 19 May, 1968, and also the editorial, "Germany's Young Left", Kai Hermann, *Encounter,* Apr. 1968.
116. A recent poll of U.S. college students showed that regarding "family life", "strong leaders", "economic security", "science and technology" and "individual freedom", the greatest number thought that too much a priority was given "science and technology" and they equally considered that too little priority was given "family life". *Newsweek,* 22 Feb. 1971, p. 61.
117. "2000: How we will live in it", *Monetary Times,* Dec. 1967.
118. Quoted by F. S. C. Northrop in *Man, Nature and God,* Simon and Schuster, N.Y., 1962, p. 63.
119. "Text of Eisenhower's Farewell Address", *The New York Times,* 18 January, 1961, p. 22. Recently Dr. Herbert York, a senior Defence Department official in President Eisenhower's government, has described in detail the dangers of such an élite; see Herbert York, *Race to Oblivion,* Simon and Schuster, New York, 1971, p. 256.
120. James M. Gavin in collaboration with Arthur T. Hadley, *Crisis Now,* Random House, N.Y. 1968, p. 9.
121. Hasan Ozbekhan, *The Triumph of Technology: 'can' implies 'ought',* System Development Corp., Santa Monica, California, (quoted by Fromm, *op. cit.,* p. 33).
122. Fromm, *op. cit.,* pp. 32-33.
123. Economic Council of Canada, *Fourth Annual Review,* Sept. 1967, p. 77.
124. Quoted by René Dubos, *Reason Awake,* Columbia University Press, New York, 1970, p. 128.
125. J. Randers and Dennis L. Meadows, "The flow of DDT in Environment from Chemical Plants to Biomass", *Project on the Predicament of Mankind,* (manuscript, The Club of Rome), p. 3.
126. *Reason Awake, op. cit.,* p. 127.
127. Quoted by René Dubos, "The Predicament of Man", *Science Policy News,* Vol. 2, No. 6, May 1971, p. 67.
128. *The World Food Problem,* A Report of the President's Science Advisory Committee, Volume 1, May 1967, p. 24.
129. Lester R. Brown, "Human Food Production as a Process in the Biosphere", *Scientific American,* September 1970, p. 170.
130. Norbert Wiener, quoted by René Dubos, *Reason Awake, op. cit.,* pp. 124-125.
131. *The Next Ninety Years.* Proceedings of a conference held at the California Institute of Technology, March 1967, edited by Richard P. Schuster, and California Institute of Technology, Pasadena, 1967.
132. René Dubos, "The Predicament of Man", *op. cit.,* p. 66.
133. *Reason Awake, op. cit.,* p. 75.
134. Quoted by René Dubos, *op. cit.,* p. 67.
135. Dennis Gabor, *Inventing the Future,* Secker & Warburg, London, 1963.

12

THE BASIS OF SCIENCE POLICY: OBJECTIVES AND FEATURES OF SCIENCE ACTIVITIES

The world of science and technology, of research, development, and innovation, and of their complex interactions is still obscure. At the beginning of Volume 1 we underlined this obvious fact: "The Committee would be naïve not to state that its report is far from providing complete and final answers to the problems that science policy ought to solve. After prolonged hearings and discussions with the leading experts in this field in the Western world, we know that no individual, no group, and no country has yet found such answers."[1] The heads of government agencies who expect this report to provide a list of specific R&D projects and programs they should immediately abandon or launch will be disappointed. The Committee does not think Canada is yet in a position to make such a detailed allocation of her scarce scientific and technological resources on a rational basis.

Before the Canadian government is ready to define the content of its science policy in detail, it must first develop broad targets and strategies for the national R&D effort, revise its methods of intervention, and drastically reorganize its agencies and administrative mechanisms. Many of these decisions will be difficult to take but they are urgently required. If they are not taken, and on a sounder basis than in the past, our country will lack the proper framework for rational choice between specific alternatives and will continue to have a science policy by accident. This is why the Committee has decided to devote the last volumes of its report to the consideration of broad targets and strategies and to the organization of a government machinery capable of attaining them effectively.

The intent of this chapter is to build a basis for determining broad targets and strategies for the national science effort and an overall, coherent science policy.

It is obvious that science policy, like all other government policies, must be designed to serve national goals in the most effective way possible. It does not follow, however, that thinking about these goals automatically determines the targets, strategies, and content of science policy.

Many representatives of the scientific community, especially among the engineers and the technologists, have told the Committee: Give us the goals and we will do the job. The Science Council of Canada, too, in its attempt to "construct a sound policy", came to the conclusion that "it had first to erect a frame of reference" based on the social, cultural, and economic objectives of society. The Council listed six goals: "national prosperity; physical and mental health and high life expectancy; a high and rising standard of education readily available to all; personal freedom, justice, and security for all in a united Canada; increasing availability of leisure and enhancement of the opportunities for personal development; world peace, based on a fair distribution of the world's existing and potential wealth."[2] The ultimate end of society is to maximize the quality of life of its members and science policy, like all other policies, should make its full contribution to this basic purpose. But this assertion is not too useful as a guide for policy. Even if it were possible to identify and agree on all the specific objectives and needs of society, it would be unrealistic to expect the national science effort to serve them *all* satisfactorily. The scientific manpower and budget required would be beyond the capacity of even the United States.

A system of priorities for national goals and problems could overcome this limitation. This would not be an easy task, especially in a democratic and pluralistic society where "objective" criteria may not coincide with the subjective priorities of the population. Yet in spite of the difficulties, advanced societies whose schedules of needs tend to become more and more complicated and inconsistent will have to find better ways of defining their national priorities. This will require more and better planning at government levels, as much as possible involving the population itself so as not to extend the inhuman aspects of bureaucracy and technocracy.

It should be noted, though, that even a satisfactory system of general priorities will not necessarily pinpoint specific priorities for the national science effort. Research requirements do not necessarily match national needs. For instance, good roads have a high priority but may require relatively little research. Moreover even though a problem, for example health, may have a high priority for the nation and require extensive research, this does not necessarily mean that the research must be conducted in the country; the

results of research carried out abroad can be imported and may meet the need better than an indigenous science effort. Thus the search for broad objectives, although useful, cannot alone provide a sound framework for the formulation of science policy.

SPECIFIC OBJECTIVES AND AREAS OF SCIENCE ACTIVITIES

The broad purposes of society can be classified into three major categories: cultural enrichment, including national prestige; economic growth; public welfare. It is on the basis of these major aims that the OECD and other agencies have recently begun to analyse and appraise science activities. The Committee fully endorses this new approach and hopes that it will be applied more systematically by international and Canadian agencies charged with the responsibility of measuring the input and output of these activities. Indeed, it is within the framework of these three major purposes that the requirements and contributions of science and technology can best be seen and that the main tasks of science policy can be most easily identified.

1. *Cultural enrichment*

Cultural enrichment must increasingly become an aim of our society. Given man's natural desire to learn, the advancement of knowledge can play a more important part in moving toward this goal.

It is often asserted that fundamental research has no purpose and is a curiosity-oriented activity. This statement is confusing. It is true that fundamental research is not primarily aimed at a practical mission. However, it has a definite purpose—scientific discovery and the advancement of pure knowledge—that makes it a vital element of our cultural life and civilization. Advanced and affluent societies in particular *must encourage basic science* for reasons similar to those demanding that they support the arts, that is to say, as a sector of high culture and disinterested intellectual activity.

Even fabulous technology can be seen as a creative act serving cultural purposes, the advancement of knowledge and the enhancement of national prestige. Man's landing on the moon and the exploration of our universe are programs with a high technological content and they may in the future produce important practical results. For the moment, however, they are designed primarily to satisfy national prestige and human curiosity.[3]

Little thought appears to be given to how science can best enrich public culture. It has been remarked that many scientists receive their degree

without ever really knowing much about science itself, at least about the overall nature of science. Is the average student's science education designed to allow him to "know science" or to have a "scientific sense"?[4] Science obviously has an important contribution to make to culture, but the means of diffusing it still seems to be virgin territory.

2. *Sustaining the economy and public welfare*

Society's second major interest in research and development centres around *the innovation process*. Through innovation society either benefits or suffers from the applications of knowledge. Innovation can be defined in broad terms as the introduction for the first time in the world of a product, a service, a method or process of production, or a policy. The innovation process is highly irregular. It may begin with pure research leading to a scientific discovery, the development of an invention based on this new knowledge, and the innovation itself. (The diffusion of innovations is also very important for society but it belongs to industrial strategy rather than science policy.)

The Committee believes that the basic purpose of mission-oriented research and development, wherever they are done, is innovation. It considers innovation to be a major goal of science policy. This means that basic or even applied science are not *in themselves* essential parts of the role of a mission-oriented agency in government or industry. They are instruments or means that should be used only when there is a good probability that they will enable the agency or others in the country to innovate. This also means that the merit of mission-oriented programs and the performance of the agencies initiating them should be measured only by the value of the innovations they introduce or help to develop. This criterion of innovation should be used not only to appraise past performances but also to plan, evaluate, and control future science activities, to determine their priorities, direction, and content.

There are two broad categories of innovations, so different in their objectives and requirements that they must be considered separately. The first group is aimed at the market place and is more related to economic growth. It results from what can be called *industrial research and development*, regardless of whether these activities are carried out by private industry or by others on its behalf. Technological innovations for the market place will become an even more important growth factor than they have been in the past—at least for as long as the increase of affluence remains a high national priority.

The second category is aimed at solving broad social problems, such as health, poverty, poor education, and pollution. More directly related to the quality of life, these could be called *social innovations,* whether or not the research and development work they require is carried out by government agencies. If our affluent society is to become healthier and happier, collective needs and problems will have to have a higher national priority, and social innovation for the public welfare will then constitute another major goal of R&D activities and therefore of science policy.

It should be noted that social innovations must in many cases involve private industry and must work within the mechanism of the public market to be successfully adopted. That doubtless was what the government of Sweden had in mind when it set up a development corporation to promote new products and processes for the amelioration of collective social problems.

Thus, the basic objectives of science policy are cultural enrichment, economic growth, and public welfare. But their requirements cannot be limited to the determination of an adequate and balanced level of indigenous R&D expenditures. The consideration of their goals and their implications must also extend to all areas affecting the input and output of the R&D effort.

3. *A balanced supply of scientific manpower*

Science policy must also be concerned with the maintenance of a balanced supply of scientific and technological manpower, including managers and administrators competent to orient the national R&D effort and use its results for the cultural, economic, and social advantage of the nation. Two requirements must be met in this area.

First, it is not enough to rely on the inclinations of students, who if left to themselves might overcrowd some professions and neglect others. Programs of scholarships and fellowships can serve to correct imbalances and must be determined by the future needs of the R&D effort. Also this must be complemented by a system of continuing education to maintain competence, and to assist the necessary mobility of R&D staff toward new problems. The brief of the Department of Energy, Mines and Resources stated:

> If it is important that recruits . . . be scientifically and technically competent, it should be equally important that they remain so, and if possible increase their competence.[5]

Second, scientists and engineers have to be trained, so an adequate teaching staff is necessary; if, as is now widely claimed, a good teacher must have the opportunity to carry on his own research, in close association

with his students, this is an additional reason to support academic R&D as an adjunct to teaching. But again, this aspect of academic research should reflect the whole spectrum of the national R&D effort if manpower requirements are to be met in terms of quantity and quality. If research in universities were confined to basic science the country would not get the applied scientists, the engineers, and the technologists it needs to produce more inventions and transform them into successful innovations. In fact, a growing number of people argue that new kinds of university education will be required.

4. *The provision of auxiliary services*

To support an effective R&D effort leading to innovations, various auxiliary services usually provided by the government are needed. Testing services, the setting of standards, and a good patent system can be most useful in the last stages of the process. Technical surveys and resource inventories are a prerequisite for the general orientation of R&D activities. Economic and social data collection constitutes an essential preliminary step, especially for social sciences and innovations. Finally, the provision of financial assistance in various forms, including equity capital for the small innovator, is a necessary ingredient if universities and industry are to perform an adequate level of R&D activities.

5. *A national information network*

It is often said that a special feature of our age is the knowledge or information explosion. It could equally be said that we are victims of the ignorance explosion, for as the stock of knowledge increases more rapidly, so does a man's potential ignorance. It is asserted that the stock of knowledge is still rising at an exponential rate, doubling every twelve years.

It is quite impossible for scientists and engineers or even individual agencies to know with any exactness what research and development activities are being done in their fields or in related areas at home and abroad at a given moment. The problem becomes more acute and crucial the closer one comes to technology and innovation; the information is less easily accessible because of commercial secrecy. And yet when the results of these activities become known they are sometimes free goods which need not be rediscovered. For a country like Canada, the rapid diffusion of new scientific and technological developments is more important than for larger nations because we cannot expect to contribute much more than 2 per cent of the world's total R&D effort. For this reason, we must know as much as we can of what goes

on abroad. A well-organized national information service is thus essential, not only to research workers and agencies but also to policy makers and administrators in government, industry and universities.

6. *Technology assessment*

Science policy must also be much more interested in the output of R&D than in the past, not only to appraise its benefits but also to try to evaluate its short-term and long-run negative effects.

Up to now, our examination of the negative impact of technology has been practically limited to food and drugs. The public's growing awareness of the much wider undesirable effects that technology can have must be reflected in substantially extended and improved assessment activities. Recent proposals to organize technology assessment on a more systematic basis have put the emphasis on the negative aspect of innovations. The Committee believes the positive side should not be neglected either, and appraisal, furthermore, should not be limited to technology but should include the output of all R&D activities, even fundamental research. Otherwise we will never know the net benefits derived from public expenditures devoted to science and technology and we will not be in a position to arrive at a rational allocation of resources.

7. *A favourable public climate for innovations*

Although it does not lie within the immediate scope of science policy, the general political climate surrounding research, development, and innovation is vitally important to the efficiency of the national R&D effort. The government approach to such policy matters as monopoly controls, patents, tariffs, taxation, the availability of risk capital, and foreign ownership may have a large impact, favourable or unfavourable, on the level of private R&D expenditures and on the volume of market-oriented innovations. Decisions on these matters are usually based on considerations that have little to do with science policy and may very well work at cross purposes with it. Those who have to implement science policy should at least be heard before such decisions are taken. These factors are discussed in more detail in Chapter 16.

THE FEATURES OF R&D ACTIVITIES

A comparison between fiscal policy and science policy illustrates a requirement of science policy. Since World War II advanced countries have assigned to fiscal policy such objectives as full employment, a fair distribution

of the national income, price stability, and a satisfactory international balance of payments. These specific goals do not, however, throw much light on the strategy and content of fiscal policy. One needs to refer to economic theory to explain the features of economic activities and the behaviour of the national economy and its main components and to evaluate the influence of various types of public expenditures and taxes. It is only when this contribution of the science of economics has been taken into account that the strategy and immediate targets of fiscal policy can be determined.

The same is true of science policy. It is important to consider objectives but only systematic analysis of the specific features of science activities, of the behaviour of the national science effort and its main components, and of the influence of the various methods of government intervention can help to develop strategies and targets to attain the objectives. In other words, a theory of science activities is needed as a basis for the national formulation of science policy.

The systematic study of the world of science, technology, and innovation, sometimes called the "science of science" or "scienomics", is just emerging as a new discipline. It is still too early to know if it will ever be possible to develop a truly scientific basis for science policy: as yet systematic studies of R&D activities are being conducted in only a few centres in the world. But certainly the need for such studies is urgent. Harvey Brooks says:

> There is increasing concern with the need for better understanding of the research process itself... Recently there has been an upsurge of interest in this area, but there is still an absence of solid generalizations based on reliable empirical studies. Much knowledge of the research process comes either from the observations of social scientists with minimal knowledge of the substance of the research area they are investigating, or from the anecdotal evidence of scientists and technologists having little appreciation of the standards of historical evidence and often inadequate appreciation of the economic, social, and cultural factors that influence the rate of adoption and application of research results... Considering the funds that the federal government devotes to such activities, a greater effort should be devoted to objective empirical studies of the process itself.[6]

One of the most important aspects of the "science of science" is the determination of how R&D is related to innovation and this requires a much fuller understanding of the whole process. A fairly recent OECD study draws attention to the fact that technological innovation has been the object of empirical analysis and data collection only during the last 10 to 15 years, which, it is said, has held back the appearance of useful generalizations of the matter. The OECD study gives a warning for Canada:

> ...it should be noted that a very high proportion of all information and analysis of technological innovation has been undertaken in the USA. Since

> the U.S. system is so well documented, and since information about it is so readily available, there is a danger ... of slipping into an almost exclusive discussion of the U.S. system ... without sufficient consideration of the different levels of resources, environmental conditions and policy objectives of the other Member countries.[7]

It is difficult to see how a satisfactory policy for government-sponsored R&D in Canada can be developed without a better understanding of the indigenous process and potential of innovation. The Science Council and a few universities have begun to develop an interest in this field, but the Committee, while noting with interest that there are some useful beginnings,[8] is surprised that on the whole there has been so little study of this matter in Canada. As Dr. M. McCarrey of the Public Service Commission puts it:

> In the face of past phenomenal growth of research and development activities in this country, social science research on research has been infinitesimal. Almost completely neglected by empirical study has been the organizational climate in which a research scientist works.[9]

The Canadian government will have to support more systematic and extensive studies. Research on research is the key to improving the formulation of science policy, developing better management techniques for R&D programs and personnel, and maximizing the overall scientific and technological output.

Even though the theory of science activities, the science of science, is still in its early stage of development, it can already make a valuable contribution to the formulation of a general strategy for science, technology, and innovation. While our reflections on the spectrum of R&D activities in the chapters following are elementary they have a significance that will become more evident as their policy implications are developed.

GENERAL FEATURES

For the initial purpose of determining broad strategies and targets, only two general characteristics of R&D will be considered.

One of the most distinctive features of R&D expenditures, including current outlays, is that *they must be recognized as investments*. The financial burden is short-run, the results are long-run. Like most projects involving capital expenditures, research and development programs must be carefully selected and planned; once initiated, they usually require several years for completion. Moreover, it is only when they have been successfully concluded that they begin to have an impact. Yet since the product of an R&D project

is knowledge, in the form of a discovery or an invention, it can be used, reproduced, and built upon until it becomes obsolete, which may take several decades.

Although R&D is considered as an investment by many R&D managers and the boards of their organizations it is different in nature from other types of investment. The nature of the risk is different but so far no one has come up with an acceptable set of decision rules. A recent OECD study cites the opinion of European research managers:

> ... there is a fairly general feeling of dissatisfaction with the existing procedures for project selection. Virtually all research managers are highly interested in formal methods for this purpose although in fact freely admitting that they do not make much use of them. Furthermore, as projects become more complex, as the rate of technological advance increases, it is becoming increasingly difficult to make satisfactory intuitive decisions. More and more, the need is being felt for rendering explicit the implicit assumptions and hypotheses upon which intuitive decisions are based. However unsatisfactory the existing formal methods may be, the use of no method at all is likely to be even worse.[10]

Although improvements need to be made in the methods of R&D project selection, it is becoming clearer that R&D is a crucial investment underlying the development and growth of industrial enterprises.[11]

R&D activities can be cut more easily than most other expenditures during periods of financial austerity, but they cannot be resumed or increased as easily as others. In the government sector, for instance, the cutting of research projects does not usually meet the same public resistance as would the lowering of family allowances or an interruption in highway construction. After all, the benefits to be derived from research are not immediate and certain. On the other hand, the reduction of R&D activities means either that research teams remain under-employed, which destroys morale and efficiency, or that they have to be disbanded, and experience shows that it is much more difficult to call back researchers than, for example, to resume a construction project. In the interim new university graduates who might have been willing to undertake a research career in Canada may decide to emigrate or to do something else and are thus permanently lost to the national science effort. As Dr. S. P. Blake, vice-president of Stanford Research Institute, said in an article:

> One thread that runs through successful programmes is that they were stably funded. This does not mean they were lavishly funded—far from it—but that the rate of supply of money was not subject to wide or sudden variation.[12]

The long-term nature of R&D activities means that they cannot be conducted effectively on the basis of annual appropriations, a system that was,

after all, originally determined by the cycle of agricultural production. More than any other, science policy must be formulated within the framework of the medium-term and long-term future.

Nevertheless, R&D teams should not be artificially kept together after their mission has been accomplished. More and more "temporary" R&D teams will have to be set up to cope with a given problem then disbanded when the objective is met. In planning research it is important to allow for mobility of staff and to ensure that staff can be reallocated or even retrained. Thus, while R&D projects and programs are of a rather long-term nature, science policy must be kept sufficiently flexible to adjust to real needs and demands for R&D rather than rely mainly on the priorities of supply as represented by the choices of R&D personnel.

A second general requirement of a sound national science effort is that *it must be determined in the light of what other countries are doing*. R&D activities are almost unlimited in scope. They cover all scientific disciplines and all branches of engineering and lead to industrial and social innovation. Any single nation attempting to cover all these fields fully would require a fantastic budget and a vast army of scientific manpower. Not even the richest country could afford to do this without sacrificing other important national objectives. It has been estimated that throughout the world approximately $50 billion are now devoted annually to research and development and yet many sectors of science activities are still not adequately supported.

On the other hand, the results of R&D activities can sometimes be imported from other countries. New ideas in certain areas constitute an easily accessible world common market. In Canada's case, a large share of new knowledge and even of innovations will have to be imported, as Canada due to her financial and manpower limitations will not be able to conduct much more than about 2 per cent of the world's R&D. Social inventions and innovations that solve broad public problems should be used when accesssible and appropriate. Market-oriented inventions and innovations can be imported and exploited under licence or even imitated. To that extent expenditures on R&D can be seen as a waste in any given country provided that others are willing to go on spending money for them and to freely share the results.

However, not even a small nation can exist simply as a parasite of the international scientific and technological community. It has a moral obligation to contribute to the international pool of knowledge if it wishes to go on fishing. It must maintain an adequate supply of scientific and technological manpower, too, if it is going to imitate and benefit from the inventions and innovations made in other countries. Experience has shown that that kind of capability cannot be maintained without some indigenous R&D activities.

Thus there are two extreme limits to the level of a nation's R&D effort. It should not be so high as to ignore the international division of labour and the fact that scientific discoveries and technological inventions can be imported. It should not be so low as to place the nation in the situation where it would neglect its international obligations and put its own future in jeopardy by becoming the victim of a widening technological gap. Within those two limits the proper level of R&D activities should vary from one country to the other according to the stage of their economic and social evolution, their specific national requirements, and their place in world affairs.

SPECIFIC FEATURES

Science policy must decide not only the size and timing of the Canadian science effort but how resources should be allocated between the main areas of R&D activities: basic research, and applied research and development leading to industrial or social innovations.

1. *Basic research*

One of the recurring questions in the literature of science policy concerns the share of the R&D effort that a country should devote to basic research.

Basic science is aimed primarily at *extending the frontiers of knowledge,* the understanding of man and his environment; it is as much an element of culture and civilization as the arts, as Alvin M. Weinberg puts it:

> There are many analogies between the purest basic research activity and artistic activity. Each is an intensely individual experience the effect of which transcends itself. The product of each is immortal—the theory of relativity, just as surely as Hamlet or the Mona Lisa. Each is concerned with truth—the highest of human manifestations—the one with scientific truth (which deals with the regularities in human experience), the other with artistic truth (which deals with the individuality of human experience). Each enriches our life in unmeasurable though highly significant ways. Each belongs not only to its creator or discoverer, but to all mankind.[13]

Because basic science improves the quality of life, each nation must make its contribution not only in its own interest and for its own prestige but for the improvement of humanity as a whole.

A second feature of basic science that justifies financial support is that *it is not as pure as it is often alleged to be.* Indeed, it would be quite easy to show that many important innovations since the first Industrial Revolution

have originated from basic research and scientific discoveries that were not at first viewed as having practical application. René Dubos tells a characteristic story about Michael Faraday:

> Shortly after he had discovered electromagnetic induction, but before it had been converted into a practical technology, Faraday received a visit from an important political personage in his laboratory at the Royal Institution in London. He demonstrated the new phenomenon to the visitor who was not impressed by Faraday's simple apparatus and inquired, "What is the good of this discovery?" Faraday replied, "Some day, sir, you will collect taxes from it."[14]

Harvey Brooks gives many illustrations of the practical contributions made by fundamental research and concludes that "the boundaries between science and technology are becoming increasingly blurred".[15] Thus if basic sciences are neglected that source of innovation will inevitably run out.

It is worth emphasizing again that if Canada were to give too low a priority to the training of pure scientists and to the support of their work, that would cut the country off from the 98 per cent of the basic research that is done abroad.

Basic research is usually the least expensive of R&D activities. It is most often associated with "Little Science"; as the Science Council puts it:

> ... there is "Little Science"—the individual scientist pursuing his interests in research in areas of his own choosing. The number of scientists who follow this course in any generation is small, but their contribution to knowledge has been high and the cost of supporting them, modest. No nation can afford not to support these people.[16]

When basic science embarks on big programs requiring heavy expenditures for large, complex, single-purpose machines, such as at CERN in Europe, it lends itself quite naturally to international co-operation, which greatly reduces the cost of national participation. Even the superpowers are co-operating more in such Big Science fields as high energy physics. For example, there is growing co-operation between Soviet high energy physicists at Protvino and U.S. scientists, the staff from CERN (who recently moved tons of research equipment to Protvino) and French scientists (who recently installed a large French-built bubble chamber[17]).

These are some of the major features of basic science that justify financial support. There are others that tend to offset these favourable features and show that support should be limited. For instance, while basic research is usually the least expensive kind of R&D it is also the least likely to reach its goal. The history of science shows that in any generation there are very few minds capable of extending the frontiers of knowledge and that even these

cannot often repeat their feat. Investment in basic science is a risky venture. There are many scientists who think they are potential Einsteins, but unfortunately very few in fact are. Dr. Gerhard Herzberg states that "there is a pyramid and not every one will come to the top.",[18] and he points out that there are many other useful tasks for scientists, such as administration.

The role of basic research in innovation should not be exaggerated. As Dr. Gerhard Herzberg stated recently:

> Modern life has been so strongly influenced by technological developments based on scientific discoveries that we are prone to over-emphasize the utilitarian aspects of science.[19]

The connection between science, technology, and innovation does not appear as close as Harvey Brooks believes it to be. Moreover, "The decreased interval between scientific discovery and widespread application in recent years"[20] does not seem to be as well documented as he pretends. These two aspects of the relationship between science and innovation deserve further consideration.

One reason why this relationship is still remote is that the translation of scientific results out of the published papers of scientists and into technological developments is inhibited by the differing goals and behaviour of scientists and engineers. This was touched upon some years ago by Dr. A. G. Mencher, scientific attaché at the American Embassy in London, who summarized the research done on the communication of technical ideas by Professor Thomas Allen of the Sloan School at MIT:

> In reviewing sources of technical ideas, Allen stresses that oral communication dominates as a channel of information, and that the literature, including trade magazines as well as professional scientific journals, are not an outstanding source. Unlike his scientist colleague, the average engineer is in fact not equipped to read the journals of his own profession, although his performance has little relation to use of the literature. Thus, according to Allen, any system relying for its effectiveness on the provision of written materials to engineers is wasted.[21]

Several other studies confirm these findings. For instance, a recent survey by Donald G. Marquis and Sumner Myers reaches the conclusion that "70% of the information used in the innovation was readily available from prior work. A network of acquaintances was proposed as the most important source of ideas and . . . the Federal Government was deemed not part of this network. Most of the information came by word of mouth and less than 10% from printed material."[22] In other words, the majority of the innovations

covered by the survey were not held up because of the lack of basic scientific research. According to W. R. Hibbard, vice-president, research and development, of the Owens-Corning Fiberglas Corporation and formerly director of the U.S. Bureau of Mines, in a speech delivered in 1969:

> The DOD [Department of Defence], which had invested 10 billion dollars in research over a 20-year period, instituted "Hindsight: an Examination of the Return on Investment in Research". The study covered the technical basis of 20 new military systems. It concluded that contributions from research in science were greatest when the effort was oriented—that it frequently takes 20 to 30 years for basic research to show up in technology and the most important aspect of the support of basic research was the education of top scientific leaders. . .
> Illinois Institute of Technology carried out a case history study for NSF [the National Science Foundation]. They reported that key research often took place 20 to 30 years prior to the innovation.[23]

The OECD study on innovation points out that although, as Hibbard says, both the Hindsight study and another study reporting on five innovations, the TRACES study, indicate the same time lag between a basic scientific discovery and its ultimate use in innovation, the conclusions of Hindsight have "sometimes been misused, as if industrial innovation were exclusively an industrial problem, without any noteworthy contribution from university research"[24]. The OECD group points out that TRACES challenged this generalization:

> Thus, TRACES sees innovation as a result of two parallel, both indispensable sources: mission-oriented research which works towards a preconceived goal, and a large pool of general knowledge, originating mainly in the university and, in number of events, more important for innovation than mission-oriented research.[25]

Given the time lag between basic scientific discovery and utilization it might seem that countries such as Canada that can only contribute a modest few per cent to the world's basic science pool would nonetheless have as good an opportunity for utilizing the science as the major powers. The TRACES study suggests that this may not be so:

> All, or almost all, of the fundamental scientific knowledge integrated into those five innovations was available to anyone, irrespective of its place of origin—in this case, mainly the U.S.A. Why, then, was almost all relevant development work leading to the five innovations being carried out within the United States too, and only little of it in other countries?[26]

Although no definitive answers are given it is clear that a country the size of Canada must develop more effective strategies for utilizing the world pool of basic science and resist any chauvinistic temptation to rely only on self-generated basic research.

The great physicist, I. I. Rabi, Nobel Prize Laureate, said in 1965: "I'm not sure that science has been so terribly important for a lot of the basic technology we have today."[27] Professor Frederick Seitz stated in 1966 when he was president of the National Academy of Sciences that ". . . matters up to 1800 probably would have continued more or less as they did if science had not developed or had remained isolated from technology".[28] However, he made an exception for chemistry and the science of electro-magnetic phenomena. The distinguished historian of science, Thomas S. Kuhn, urges his readers to treat science and technology as quite distinct activities and adds: "Starting from this perspective one can ask, as the socioeconomic historian must, about interactions between the two enterprises, now seen as distinct."[29]

Kuhn, like Seitz, notes the more intimate relationship between science and technology in the German dye and electrical industries in the 19th century but cautions that there were unique institutional reasons for this transformation, the role of Germany's technical colleges (Technische Hochschulen), and that a proper understanding of this would make "many current debates over science policy . . . more fruitful . . . ".[30]

During the Senate Committee's hearings this same point was made by Dr. G. A. Harrower, dean of the faculty of arts and sciences of Queen's University, who said that the social justification for science lies in the application of the fundamental principles discovered by science but "it requires something like a 25-year lead time".[31]

Mr. Vernon O. Marquez, President of Northern Electric, went even further when he told the Committee "the connection between knowledge and its translation into usable goods or services may not take place for a hundred years. There is very little connection."[32]

Another, and recent, witness on this subject is the British scientist Lord Rothschild, head of the Central Policy Review Staff of the British government. In his recent paper, *A Framework for Government Research and Development,*[33] Lord Rothschild notes that many spokesmen of science claim that basic science is indivisible from applied science; the latter view believes "that the adjectives pure and applied [research] imply a division where none should exist and that their use can be harmful" and Lord Rothschild goes on to comment that "this view is not easy to understand." He allows that

> It is not, of course, in dispute that the results of pure research may sometimes be of applied or practical value, and that applied research may produce results of 'pure' interest and importance.

but goes on to conclude that

> The government should, therefore, reject the view that there is no logical division between pure and applied research. . . .[34]

The Committee could quote many other authors and studies to justify its conclusion that the worlds of science and technology, of the pure scientist and the engineer are still very different, although they may tend to influence each other more now than in the past.

Another important feature of basic research is that of the whole range of R&D activities it is the most readily available in printed form. The main motivation of the true scientist is not only to discover but to develop and maintain his reputation among his peers through the publication of his findings. For this reason indigenous scientific discoveries are important for individual and national prestige: but as far as promoting indigenous innovations is concerned, it does not really matter if they are made abroad, provided a national capability to understand and use them is maintained. In other words, basic science is a free good. It can be imported without risk, cost, or delay. The results of fundamental research have a similar character. If they are successful in bringing new scientific discoveries, they merely add to the international pool of knowledge. This feature is particularly important for a medium-sized country like Canada.

The OECD summed up an exhaustive survey of some features of fundamental research in this sentence:

> The characteristics of such research are often very low probability of success, relatively low cost, very high pay-off if successful, but pay-off only in the long term—up to thirty years according to the evidence presented elsewhere in this report.[35]

Obviously, if these findings are correct, they have important implications for science policy. They show that scientists and engineers, who fulfil quite distinct roles in the innovative process, have different mentalities, habits, and lines of communication. They also indicate something about the relationship between research and discovery, on the one hand, and development and innovation on the other. It is rarely close, for one thing. Innovation can take place without having been preceded by research, for another. When scientific discoveries are transformed into innovations the process takes a long time. It is exceptional when the innovative process flows in unbroken sequence from basic research to production. Thus "the utilitarian aspects of science" should not be overemphasized. Curiosity-oriented basic research does not have a high priority, at least in the short run, when it is considered

in the perspective of innovation. It must be remembered, however, that innovation must often be backed up by mission-oriented basic research and that projects of advanced technology require the support of first-class researchers working in fields of basic science connected with the high technology involved.

2. *Industrial R&D*

The design and development work leading to market innovation, which is mainly carried out by industry, is at the other end of the R&D spectrum from basic research. Market-oriented R&D may cover a wide range of activities, including oriented basic research when necessary. The sequence can begin with applied research, which uses the findings of basic science to increase knowledge in a particular area, but consists mainly of development work, which starts with the immediate steps leading to an invention and includes design, testing, tooling, market analysis, and other activities preceding the introduction of an innovation on the market. (The stimulus for the innovation, it should be added, usually comes from market needs rather than technological opportunities. The OECD report on innovation suggests that market needs are responsible for about 70 per cent of innovations.)[36]

Development leading to invention and innovation is primarily the work of the engineer and the manager, and in their practical world, research becomes a tool, a means, a derived activity. The ultimate goals of industrial development work are to bring profits to the individual firm and economic growth and affluence to the nation through the introduction of technological innovations on the market. Thus the characteristics of industrial R&D are quite different from those of fundamental research.

A country can make technological progress in three different ways. It can merely import the new products or processes, and inevitably will in many cases because no country can be self-sufficient. In terms of employment and growth, though, this is not a very useful way of benefiting from the application of new knowledge and innovations. The other two alternatives are the production of imitations, and indigenous innovations originating from inventions made at home or abroad. Here again imitation is often the most practical solution, especially for a small nation. The point is, however, that indigenous innovation, the introduction for the first time on the market of a new product or a new process, generally yields more profits and more growth and affluence than imitation.

Professor Raymond Vernon of Harvard University and others have developed a theory of international trade based on the three stages of the "products cycle". John L. Orr has summarized this theory:

> At the first stage, the innovating country has a seller's market due to its technological lead and therefore is readily able to surmount tariff barriers, and thus develop substantial export sales. It is at this stage that the highest financial returns are realized.
>
> As the product design matures, and the demand in foreign markets grows, competition may develop by imitation, or licensing to producers in other advanced countries, which have the requisite industrial capability. Eventually, when the product design becomes standardized, and foreign producers can exploit favourable economic factors, the innovating country may become a net importer (as in the case of transistor radios imported into the U.S. from Japan). At this stage, price competition is very keen and the advanced nations may find it difficult to compete with mass production from the less-developed countries.
>
> The implications of this theory are important for the smaller industrial nations such as Canada since it shows how our industry can exploit the "dynamic comparative advantage" of technological advances even though our home market is of limited size.[87]

If Canadians had been better innovators, fewer Canadian manufacturers would be restricted to the small Canadian market, more would be selling abroad, and Canada would be host to fewer foreign subsidiaries.

The results of industrial development work, however, are much less readily available than basic research results and it becomes costly and at times almost impossible to import and use them effectively as the later stages of the innovative process are reached.

Scientists derive a great deal of satisfaction, for example in terms of international recognition, when they communicate their discoveries to others. Inventors on the other hand usually seek different rewards; they hope their inventions will have an economic value and, whether they work for themselves or for others, they have an interest in keeping what they are doing secret, at least until they can apply for a patent. This is the reason information about new inventions does not move as easily and freely as scientific information. However, when this information cannot be obtained freely through a system of technological intelligence, patents can usually be bought or exploited under licence and in this way information secured outside the firm or the country can be substituted for indigenous invention-oriented R&D. But this substitution is far from being as perfect and advantageous as it is for basic research.

The development work required to transform an invention into a successful innovation ready to be introduced on the market is even more difficult to replace. This operation, typically involving design, testing, tooling, the building of prototypes, and market surveys, has to be done by the innovating firm or country. The assertion has been made that the Japanese owe a great deal of their industrial success to imitation. This is true only in one respect: they set up an effective network to gather technological information and they have often imitated or used inventions made by others. But they have also been good innovators and they have concentrated on the development required to transform an invention into an innovation. Indeed, when market innovation, as opposed to scientific discovery, is the objective of R&D activities, indigenous development work becomes more and more essential.

In the future market-oriented innovations will become more and more a key factor for Canadian growth. They were an essential feature of the development of such countries as Japan and Switzerland and, to a lesser extent, Sweden and West Germany, which are short of natural resources. Other countries, such as Great Britain, gradually moved into the same situation as coal lost its leading economic role. Traditionally, however, resource-rich Canada has tended to take technology for granted and has merely tried to adjust to it while protecting its domestic manufacturing industries; in the process it has experienced rapid economic growth.

That particular phase of Canadian industrial history may have run its course. In the 19th century, when the first Industrial Revolution gained its full momentum, we imported the new technology and launched the National Policy (1879) to protect our new industries from foreign competition. We became late imitators and protectionists rather than innovators, and indeed protectionism is still viewed today by a significant part of our manufacturing industries as a more reliable alternative than research, development, and innovation. During that early period we suffered from secular stagnation. When the second Industrial Revolution developed at the turn of the century we were again late imitators. But this time we were fortunate enough to have the natural resources required by the new technology and since the Americans did not have enough of them to meet their needs, we were able to develop new export industries based on our national wealth. Thus imported technology and the exploitation of our natural resources became a substitute for indigenous innovation.

Those two business attitudes, the reliance on protectionism and the exploitation of resources, have together contributed to the weakness of industrial research and the innovative spirit in Canada. They have already hampered

the balanced growth of the Canadian economy and they will be much more harmful as we move into the third and permanent technological revolution and as the international scientific race gains momentum.

In the future market-oriented technological innovation will be more and more strategic as a cause of economic growth. This means that indigenous industrial R&D is now becoming a vital necessity. We must stress, however, that R&D is not enough by itself. As well as filling the "technological gap" it is necessary to fill the "management gap"—the need for the skilled manager and technological entrepreneur who uses R&D only as a part of an overall strategy for innovation.

It ought to be said that market-oriented innovation is not linked indissolubly with unfettered economic growth; it is not the unfailing engine of overproduction. It is just as importantly linked to *sustaining* the economy and providing the materials, tools, and processes people require to meet their needs and attain their purposes. Although innovation is an important ingredient for increasing economic growth it is an essential element in preventing economic decline.

The innovative capability is simply the ability to cause change in order to cope with change. To equate innovation merely with economic growth is to belittle the long-term importance of innovative capability. As we indicated in Chapter 11, a mindless economic growth cannot proceed forever, but more innovative ability—and market-oriented innovation—will probably be needed to sustain a stable economy than to increase economic activity.

These observations about innovation's contribution to the development of the nation apply equally to individual firms. The economist Peter Drucker has noted that not only products but companies themselves are now changing, appearing, and disappearing at a rapid rate:

> Of the hundred largest manufacturing companies in the United States only thirty years ago, more than half have disappeared from the list today. Some have vanished altogether, others have fallen way behind. Their places have largely been taken by companies which, thirty years ago, either did not exist at all or were insignificant. *The newcomers owe their present position not to financial manipulation but to new technology, new processes, or new products —that is, to innovation.*[38] [Emphasis added]

In this respect as in so many others, the United States is giving us a preview of things to come in the Western world. With the increasing speed of the international technological race, the situation noted by Drucker will become much more widespread. Canadian industry will have to innovate much more than in the past if it wants to grow or even to survive.

Development work lies at the opposite end of the R&D spectrum from basic research in other attributes, too. It may be the least risky but it is certainly the most expensive kind of operation in the whole science effort. But the impression must not be left that it is easy to invent and to innovate.

Invention is a complex creative activity. It requires a unique imagination as well as an adequate knowledge of the laws of nature and the attitudes of man. Many good ideas have never been realized. Even when they are, as the history of technology shows, most inventions are never transformed into innovations. The cost, performance, and market possibilities of the new product or process have to be considered. Inventions can be untimely in terms of related technologies or of social and psychological habits. For instance, telephone with television was technically possible several years ago but it was only considered feasible for the market with the development of solid state circuitry and other technology such as the silicon target vidicon. For other reasons the invention of the Pill would have been untimely if it had occurred in the 19th century.

So the diffusion of new inventions depends not only on the spread of knowledge but also on human values and behaviour. Sometimes on both: in the case of the "picture phone", its acceptance could be limited by human values for it is being introduced into one of the most intimate of human activities, communication.

Today technological advances can be forecast with greater accuracy and planned more carefully than even ten years ago. The invention process is becoming more regular and less accidental. The stages involving the transformation of an invention into an innovation are even less risky and more easily predictable. They require above all experienced engineering, competent market analysis, and dynamic management.

As Dr. A. B. Kinzel, formerly of Union Carbide, points out:

> My own philosophy has always been that there are few excuses for a development project not going into production. An unforeseen external happening, such as the issuance of a patent on the work in question, the discovery of a better way of doing it, or the disappearance of the market can cause . . . spending . . . on development engineering, without going into production and sales. But happenings like these should be very few.[39]

What is more likely to interrupt the innovation of an invention today is the question of its social acceptability.

The process also becomes more expensive as it reaches the production stage. The costs of successive operations leading to innovation vary of

course, with each project. In 1967 the Panel on Invention and Innovation established by the Secretary of Commerce of the United States gave some empirical figures that illustrate the general pattern of cost distribution:[40]

[*Activity*]	[*Percentage of Total Cost*]
Research—Advanced Development—Basic Invention	5 - 10
Engineering and Designing The Product	10 - 20
Tooling—Manufacturing Engineering (Getting Ready for Manufacture)	40 - 60
Manufacturing Start-up Expenses	5 - 15
Marketing Start-up Expenses	10 - 25

Dr. Kinzel gives a comparable cost distribution on the basis of his own experiences:

> For any given successful project, if $1 is spent in basic research, $10 will be spent on product and process research, $100 to engineer it for plant and market studies and $1,000 for the plant.[41]

Dr. A. G. Mencher describes the results of empirical research in these terms:

> Project management studies have been made by Sloan School investigators on 50 projects sponsored by various US government agencies. These projects were performed on a cost plus fixed fee basis and averaged $8 million each with a typical annual cost of $3 million. Project managers and government monitoring authorities were in close agreement on the distribution of effort among the projects. The effort tended to follow the pattern of basic research (none!), applied research (15 per cent) and advanced development (40 per cent). This is a reasonably typical distribution for commercially oriented R and D activity in industry, whether sponsored internally or solely by the government.[42]

These and other observations agree on at least two points: in the process of market-oriented innovation, development work is much more expensive than research, basic and applied; and costs rise as the last stages preceding production are reached.

There is a current view that only big and wealthy nations and large multi-national corporations can successfully participate in the international technological race and that their enormous power puts them in a position to dominate the invention and innovation scene. This is not entirely true, but there are areas where costs are so high that they exceed the financial capacity of small nations and companies. For instance it has been estimated that R&D expenditures run as high as "$200 million for an aircraft engine, $500 million for a subsonic jet aircraft, and still higher for spacecraft and supersonic transport aircraft".[43] The recent experience of the Rolls Royce Company is a clear example of the financial dangers associated with the development of products of this kind.

The giant corporation is in a position to win the race whenever it really wants to. However, it also has definite shortcomings. It generally tends to evolve new processes rather than introduce new products, as Harold W. Fisher of the Standard Oil Company (New Jersey) has explained:

> Because the large company already has a large going business to nurture, it leans toward evolutionary innovation rather than radical change. Further, these innovations tend to be process-oriented rather than product-oriented. It is easier for the large company to modify and improve the going business than to strike out into new fields. When growth requirements dictate entry into new areas, top management must make special efforts to create the organizational channels and permissive climate that allow the corporate entrepreneur to function effectively. Small companies, on the other hand, differ in important respects, including the size of the commitment to a going business. Consequently product innovations seem to occur more frequently among them.[44]

A recent OECD paper also discusses the "division of labour" between large and small firms:

> Small firms can and do make significant contributions to technological innovation in areas where production is on a relatively small scale, where the number of customers is small but their technological sophistication high, and where development costs are low...
> In many cases, large firms are not interested in entering new ventures which do not offer big markets, and they leave these to smaller firms ...[45]

The OECD paper goes on to stress that the relationships between large and small innovative firms are "not stable or fixed for ever . . . there is a continuous change in these relationships".[46]

Although there is growing evidence to show that individuals and small firms are producing a diminishing share of innovations, small firms can still innovate sucessfully, as the U.S. Panel on Invention and Innovation has reported:

> . . . independent inventors (including inventor-entrepreneurs) and small technologically-based companies are responsible for a remarkable percentage of the important inventions and innovations of this century—a much larger percentage than their relative investment in these activities would suggest.
>
> Professor John Jewkes, et al, showed that out of 61 important inventions and innovations of the 20th century, which the authors selected for analysis, over half . . . stemmed from independent inventors or small firms.
>
> Professor Daniel Hamberg of the University of Maryland studied major inventions made during the decade 1946-55 and found that over two-thirds of them resulted from the work of independent inventors and small companies.
>
> Professor Merton Peck of Harvard studied 149 inventions in aluminum welding, fabricating techniques and aluminum finishing. Major producers accounted for only one of seven important inventions.
>
> Professor Hamberg also studied 13 major innovations in the American steel industry—four came from inventions in European companies, seven from independent inventors, and none from inventions by the American steel companies.
>
> Professor John Enos of the Massachusetts Institute of Technology studied what were considered seven major inventions in the refining and cracking of petroleum—all seven were made by independent inventors. The contributions of large companies were largely in the area of improvement inventions.[47]

Patrick E. Haggerty of Texas Instruments has described five factors that inhibit innovation in the large corporation. His comments are reproduced as Appendix "1" to this chapter because they clarify a crucial element of development strategy by showing that the technological game is not the exclusive preserve of giant corporations and that small firms, and by analogy small nations, can be quite successful as participants in the invention and innovation process.

These observations on the main features of industrial R&D will be useful later in considering a global strategy for science, technology, and innovation. They show that, within the framework of the national science effort, industrial R&D aimed at market-oriented innovations is certainly less disinterested and more "ephemeral" than fundamental research. On the other hand, as indigenous innovation becomes an increasingly important factor in economic growth, development activities will be more necessary at the

national level because their results cannot be easily imported, especially in the last stages of the innovative process. It is precisely at these stages that they become less risky and most expensive. It should also be noted that while giant corporations can be highly successful in improving existing products and in developing new processes, small firms show a relatively better performance when it comes to the introduction of new products on the market.

3. *Social R&D*

Since the Committee intends to deal with the social innovation process in a subsequent volume, it will not at this stage describe the specific features of R&D activities related to this type of innovation. We believe that this analysis will be more useful if it is related immediately to the targets and strategies that Canada should adopt in this important area.

CONCLUSION

The specific objectives of the national science effort—cultural enrichment, sustaining the economy through market-oriented innovation, public welfare, and the improvement of the quality of life through social innovation—are accompanied by more immediate goals that must be served to sustain that effort and ensure its optimum output. But these immediate goals can only be clarified and made more specific by empirical observations on the various features of the different types of R&D activities. Although research on research, or the empirical studies on this latter aspect of R&D, are still in an early stage of development, the observations we have derived from these surveys with respect to basic research and the industrial innovation process are, in our view, sufficiently valid to serve as a basis for the determination of targets and strategies in those two sectors within the perspective of the ultimate objectives that they are designed to serve.

NOTES AND REFERENCES

1. A Science Policy for Canada, Volume 1, *op. cit.*, p. 16.
2. Science Council of Canada, Report No. 4, *Towards a National Science Policy for Canada*, 1968, p. 13.
3. Regarding the U.S. Apollo project, see John M. Logsdon, *The Decision to go to the Moon*, M.I.T. Press, Cambridge, 1970.
4. To paraphrase Professor Elting Morrison's remarks concerning history. Quoted by Charles E. Silberman, in *Crisis in the Classroom*, Random House, New York, 1970, p. 330.

5. Senate Special Committee on Science Policy, *Proceedings* No. 16, Appendix 14, p. 2416.
6. Harvey Brooks, *The Government of Science,* The M.I.T. Press, Cambridge, 1968, pp. 289-291.
7. *The Conditions for success in Technological Innovation,* OECD, Paris, 1971, p. 23.
8. Peter Meyboom, "Technological Innovation in Canada", Working Paper No. 7100, Department of Finance, Ottawa, 1970, (mimeo).
9. M. McCarrey, "Research Climate and Scientific Accomplishment: An interview with Gerhard Herzberg", *Studies in Personnel Psychology,* April 1971, Vol. 3, No. 1 (22-32).
10. Quoted in *The Conditions for Success . . ., op. cit.,* p. 71.
11. A recent survey is that of William N. Leonard, "Research and Development in Industrial Growth", *Journal of Political Economy,* Mar./Apr. 1971, pp. 232-256.
12. S. P. Blake, "The Seven Pillars of Wisdom", *Science Journal,* June 1969, p. 84.
13. Alvin M. Weinberg, "Criteria for Scientific Choice II: The Two Cultures", *Criteria for Scientific Development: Public Policy and National Goals,* ed. Edward Shils, The M.I.T. Press, 1968, p. 85.
14. René Dubos, *Reason Awake, op. cit.,* p. 43.
15. Brooks, *op. cit.,* p. 292.
16. Science Council of Canada, *op. cit.,* p. 4.
17. Theodore Shabad, "Facility May Aid Subatomic Study", *The New York Times,* Monday October 18, 1971.
18. Quoted by McCarrey, *Studies in Personnel Psychology, op. cit.,* p. 31.
19. Gerhard Herzberg, "The Dangers of Science Policy to the Creative Scientist", *Science Forum,* February 1970, pp. 27-28.
20. Brooks, *op. cit.,* p. 292.
21. A. G. Mencher, "Filtering Facts from Folklore" (Part 1 of "Two Strategies for R&D Managers"), *Science Journal,* June 1969, p. 82.
22. Walter R. Hibbard Jr., "Materials R&D: Planning, Programming, Budgeting and Measurement", *Transactions of American Society for Metals,* Vol. LXII, March/June/September/December 1969, p. 1032. (The survey by D. G. Marquis and S. Myers is entitled *Successful Industrial Innovations,* National Science Foundation, 1969.)
23. Hibbard, *op. cit.,* p. 1032. (For further references, see the following: "Hindsight", *Science,* Nov. 1966, p. 872; Isenson, R.S., "Technological Forecasting Lessons from Project Hindsight", *Technological Forecasting for Industry and Government,* ed. J. R. Bright, Prentice Hall, 1968; Tarrenbaum, M., "Study of Research/Engineering Interactions in Materials Science and Technology", *Coupling Research and Production,* ed. Martin and Willens, Interscience Publishers, 1967.)
24. *The Conditions for Success . . ., op. cit.,* p. 84.
25. Ibid.
26. Ibid., pp. 84-85.
27. Quoted by René Dubos, *Reason Awake, op. cit.,* p. 127.
28. Ibid., p. 81.
29. Thomas S. Kuhn, "The Relations Between History and History of Science", *Daedalus,* Spring 1971, p. 285.
30. Ibid., p. 284.
31. Senate Special Committee on Science Policy, *Proceedings* No. 47, May 28, 1969, p. 5923.
32. Ibid., No. 68, 19 June 1969, p. 8126.
33. HMSO, London, November, 1971, Cmnd 4814.
34. Ibid., p. 10.
35. *The Conditions for Success . . .,* OECD, *op. cit.,* p. 66.
36. Ibid., p. 32. (The importance of the market to innovation is described, for example, by Theodore Levitt in *The Marketing Mode,* McGraw-Hill, 1969.)
37. J. L. Orr, "A Technological Strategy for Industrial Development" (a paper presented to the Seminar on "A Nation Plans its Engineering Research", Montreal 1968), published in *Industrial Canada,* January, 1969, pp. 18-19.
38. Peter Drucker, quoted by John Kettle, "2000, Part V/The Plow and the Computer", *Monetary Times,* May 1967, p. 26.

39. Augustus B. Kinzel, "Industrial Research—Why, How and What" (paper delivered July 17, 1967), *Man and His World: The Noranda Lectures, Expo '67,* University of Toronto Press, 1968, pp. 139-140.
40. *Technological Innovation: Its Environment and Management,* U.S. Gov't Printing Office, Washington, 1967, p. 9.
41. Kinzel, *op. cit.,* p. 139.
42. A. G. Mencher, *op. cit.,* p. 83.
43. Alan H. Cottrell, "Technological Thresholds", *The Process of Technological Innovation* National Academy of Sciences, Washington, 1969, p. 51.
44. Harold W. Fisher, "Innovation in a Large Company", in *The Process of Technological Innovation, op. cit.,* pp. 18-19.
45. *The Conditions for Success . . . , op. cit.,* p. 38.
46. Ibid., p. 51.
47. *Technological Innovation: Its Environment and Management, op. cit.,* pp. 16-17.

APPENDIX 1

EXTRACT FROM THE ARTICLE OF PATRICK E. HAGGERTY IN "*THE PROCESS OF TECHNOLOGICAL INNOVATION*"

Nevertheless, I think that those of us who have been involved in invention and innovation, both in small and large organizations, agree that it often becomes more difficult as the organization grows and that a disproportionate effort seems to be involved in achieving the same amount of invention and innovation that occurred when the institution was younger and smaller. This recognition of increasing difficulty in bringing about innovation as the institution grows is usually accompanied by an acute feeling of frustration because it is so obvious that it should not be that way. As the organization grows, it has more resources, more knowledge, more qualified people, more contacts with customers, more opportunities, and greater need for innovation. Innovation ought to be getting easier instead of harder. Why is it not?

Here are what I believe to be some of the reasons:

1. As the organization grows, it becomes more complex. Hundreds and then thousands of people are involved, often at several locations. The number of customers grows. Operations extend into many states and frequently into many countries. Governments add complexities of reporting and regulation—some of them necessary but irksome and some of them unnecessary and cumbersome. To fully exploit the invention or innovation and to attain broad distribution, the price must come down. The margin between price and cost narrows. At a relatively early stage in the development, as far as this invention or innovation is concerned, it becomes far more important that the principal managers be good administrators than good innovators. The administration in a technologically based business may often require good or even highly advanced technical skill, but at this stage what counts is the aid that knowledge brings to administration rather than to innovation.

   If the organization is going to develop and grow, it must do so profitably. This can be exceedingly difficult, of course. Quite understandably we begin to get a preponderance of what I call "administrative managers". They can exploit the innovation, but the skills they need and admire in themselves, in their peers, and in their superiors and subordinates are skills of administration, including leadership. Hence, the people they need and select are, in turn, predominantly administrative managers.

   After a while, the cycle of exploitation of the innovation approaches maturity. However competent they may be and however secure they may feel in operating and adding to the organization, most of the good men now in positions of responsibility do not really comprehend the process of innovation. Often they have succeeded or displaced the original innovators, and sometimes they

have suffered justifiable despair at the inability of the innovators to perform adequately the increasingly difficult administrative tasks. At the same time, however, many an innovator fails to recognize how poor an administrator he really is. His own experience and value system simply do not qualify him to comprehend what is involved, how difficult it is to get the administrative management job done, and how justified the administrative manager is in his despair.

As a consequence, the administrative managers have no basis on which to judge and respect the contributions that the innovator can make. All they are able to see is his often inadequate ability to administer. So, they help to develop the organization by accretion, adding the products and services that flow naturally from the business they are already in, supplementing the markets in which they are already engaged, doing effective work in cutting costs and lowering prices. All of these factors are essential, but none is likely to provide the step function in product and service that is necessary for dynamic growth.

Aware of the desirability and pressure for growth at this stage, or even earlier, they begin to go down the acquisition and merger route. Because they are efficient administrators, the net result is often constructive and usually results in a more effective organization that is more profitable and more useful to society. But, at the same time, the merger makes the organization still more complex and decreases the relative number of those who know how to innovate, so innovation becomes increasingly harder. At some point the growth rate slows down or falls below that of the industries in which the organization exists.

2. For the reasons enumerated, most of the status symbols—department managerships, administrative staff managerships, officerships, and perquisites—go to the administrative managers. The innovators around the organization begin to believe, with some justification, that the way to be promoted is to succeed at administration. Some do succeed and become good administrators, and their knowledge of both innovation and administration may make the crucial difference in whether the organization stagnates or continues to innovate and grow. However, with the system as it is, many of these men will not fit the pattern that the administrative manager recognizes, and all too rarely will they get the time and the right kind of experience to succeed at administration. Too often they will "top out" well down in the management hierarchy; or if they do progress, just because they are not very good at administration, they have to work frantically to keep up and therefore will possess neither the energy nor the opportunity to innovate.

3. As the technologically based organization grows, even when it succeeds in making the innovators into good administrative managers, it can confuse continued and competent technological development and commercial exploitation of its initial innovation with successful continued innovation. Where there are many scientists and engineers doing good science and engineering, accom-

panied by technically trained managers—all working long hours and running the business at a profit and with some growth—and the tasks being performed are difficult and require all their professional skills, it can be difficult to recognize that there is no longer the requisite amount of really innovative effort going on to provide a step function in growth. In essence, the company is being consumed by its own success. After all, if the innovation is to be exploited to the degree necessary to bring all advantage due, every proper technical and commercial potential must be turned into a reality. To do so and yet to remain competitive and profitable can consume more time and energy than all the organization's best people, including the innovators, can find.

4. So, to handle the growth and the increasing complexity, the organization decentralizes into groups, divisions, departments, and branches. The total job is divided into a size that allows a good administrative manager to get his arms around it. This is logical and good management practice, but unless each general manager understands his job thoroughly, the company is in danger of becoming no more than the sum total of the decentralized parts loosely governed, from a financial point of view, at the corporate level. Then the biggest job the corporation can handle has to be related to the biggest job that one or, at the most, a few of the decentralized units working together can handle. The only way that this can be prevented is to tie the decentralized entities together strongly at the top. Top-notch general managers, aided by strong functional organizations in marketing, research and development, personnel, and control, must knit together the decentralized line units. Every manager must understand that the frequently enunciated management rule about responsibility and authority always going together is just not so.

The correct rule is that responsibility and authority must go together to the maximum extent possible. However, in a decentralized organization the span of responsibility practically always exceeds the span of authority, and each manager has an authority that extends only to his own decentralized unit but a responsibility that extends across the corporation. Without some countervailing force, even when good innovative managers develop in a decentralized organization, their innovations are generally restricted only to the entity for which they are responsible or, at most, barely beyond it. Hence, although the organization as a whole may have far more of the tools, the opportunity, and the skilled people needed for innovation, the exposure of any one manager is restricted, and he simply fails to see those larger opportunities to solve problems that are the right scale for the whole corporation or a large part of it.

Because the innovative efforts, even when they exist, tend to be restricted by the size of the decentralized units, there are few or none of what I call "breakthrough strategies". In other words, there are few strategic and innovative courses of action that, if they suceed, will have a major impact on the whole corporation—the sort of single strategy, the success of which can produce 10 percent growth rates per year all by itself, even in a large corporation.

5. For every good man in a successful organization, there is always more work than he can possibly do. Consequently, the personal discipline involved in balancing how much of the organization's limited time shall go into exploitation and how much into further innovation is exceedingly difficult. This is particularly true because when one must choose between the hazy and uncertain high-risk future associated with a major innovative effort and the tangible, quantifiable future of exploiting present technological and commercial possibilities, the temptation is almost irresistible to stress the latter and postpone the former. If one is an administrative manager whose accomplishment is unquestioned the necessity for choice may not even suggest itself.

13

BROAD FRAMEWORK AND TARGET FOR SCIENCE POLICY FOR THE SEVENTIES

The present basis for the formulation of science policy is far from ideal. A clearer identification of its specific purposes and objectives and a more complete comparison of our scientific, technological, and innovative capacity and performance with those of other nations would certainly improve it. Research on research and on the innovative process could make an even more important contribution. Chapter 12 was an attempt to improve the foundation for science policy; but obviously more extensive and systematic studies of the Canadian scene are needed if we are to deploy our limited resources in the most effective way.

Even with a greater effort in this direction, the formulation of science policy will never be an easy task. It presents difficulties as great as those of macro-economic policy. The field is wide, heterogeneous, and rapidly changing. It involves variables than can hardly be measured except in broad qualitative terms, at least at this stage, and choices between programs that are almost impossible to evaluate by common standards. As Alvin M. Weinberg says:

> ... how can one measure the merit of behavioural sciences and nuclear energy on the same scale of values? Yet the choices between scientific fields will eventually have to be made whether we like it or not. Criteria for scientific choice will be most useful only if they *can* be applied to seemingly incommensurable situations.[1]

Even if the basis for determining the content of science policy were ideal, it would be naïve to expect that such a policy could be defined once and for all. Science and technology, which are the objects of that policy, will change at a faster pace in the future than in the recent past, and that is also true of

the economic and social problems they will help to solve and create. Thus the targets, methods, and content of science policy will have to remain under constant review and to be submitted to continuous redefinition.

These limitations and difficulties should not be used as a pretext for doing nothing and for continuing to rely on haphazard and unco-ordinated decisions and actions. On the contrary, the complexities involved in the formulation of science policy and the vital importance that such a policy has for the future of our society should convince us to do everything possible to ensure a more coherent approach and better co-ordinated decisions by the Canadian government in this field. In the early stages the method of trial and error will have to be used more often than not. This has been the case in many other fields of government intervention. But management scientists now recognize that it is essential to try to formulate systematic policy even if the framework of knowledge is inadequate, the alternatives being policy by accident or no policy at all. Some of the improvements needed in the Canadian science effort are so obvious that the danger of making mistakes in implementing new policies is minimal. Furthermore, much more can be done by applying good management techniques to ensure that the improved structures we recommend later will "learn" from experience—from "trial and error"—and that they will adapt more rapidly to changing conditions than in the past.

THE STUDY OF THE FUTURE

It has been pointed out in the preceding chapters that R&D activities are long-term in nature and that one of their basic requirements for success is stable funding. This means that they cannot be properly organized and conducted on the basis of a system of annual budgeting. Such a system is clearly undesirable for industry and universities but especially for governments, because the public sector has a great influence on the other two through its incentives and grants schemes. R&D expenditures, both private and public, must be selected and financed in the context of a long period. This long-term approach is not only desirable, it is also becoming more practicable.

The framework for science and technology policy decisions is becoming more future-oriented and this should lead to more rational choices over longer periods. The goals, problems, and options that lie ahead are not completely unknown to us, we have some knowledge of the future, and by study we can attempt to understand some of the things we must do to achieve our long-term objectives. Hence, there is a science of the future, to use *science* in one of its proper meanings (i.e. *scientia,* knowledge). Some call this new

science "futurology", while Dennis Gabor suggests the term "futuristics".[2] Technological forecasting in particular is opening new avenues that were not available ten years ago. Erich Jantsch has reviewed the new tools and institutions recently developed in this sector.[3] Although some feel that speculation about the year 2000, which has become so popular recently, still looks rather like science fiction, a growing number of scientists throughout the Western world are developing a more systematic approach to long-term studies of the future. The Commission on the Year 2000 of the American Academy of Arts and Sciences, the Hudson Institute, and the System Dynamics Group at M.I.T. in the United States, the Committee on the Next Thirty Years in the United Kingdom, the "Futuribles" in France, and the Institute for Questions of the Future in West Germany are just a few examples of the new trend. Even big private corporations, such as Imperial Chemical Industries and Ciba-Geigy, are themselves undertaking long-term studies of the future, and nearly 100 major companies—Canadian, American, European, Japanese, and Latin American—are taking part in the Hudson Institute's four-year study of the period 1975-1985.

Studies of the distant future, although useful, must be highly speculative. They should be complemented by more systematic consideration of the basic options we are likely to face for 1985. The methods and techniques already available for evaluating future alternatives and for forecasting technological change and its impact on society are much more reliable when used to look at this shorter period. Such medium-term studies can become practical guides for future-oriented action, including the planning and selection of national R&D activities, which usually do not produce tangible results until several years after they have been initiated.

In Canada there are few significant efforts in this important field of investigation. The Gordon Commission on Canada's economic prospects was one of the first systematic and scientific attempts to examine the distant future, but its work was not continued. The Economic Council of Canada is already empowered to look at the long-term future of many aspects of our national life and should do so, while at the same time expanding its activities in the social domain in collaboration with universities and other interested institutions, including the Science Council. The Committee's view is that it has not paid sufficient attention to this area.

Canada certainly needs, as a start, a lookout institution that is broadly based and that can examine economic and social matters and questions raised by science and technology: in short, a centre that can survey the whole panorama of human activity as it may develop in the medium and long-term future in Canada, with an eye on the world framework.

The Committee recommends, therefore, that the Economic Council should enlarge its activities and establish a special Committee on the Future, with broad terms of reference but looking more specifically at the years 2000 and 1985 and attempting to project various possible environments that could emerge from the extrapolation of identifiable Canadian trends within the international context.

Daniel Bell has described this approach to the study of the future:

> It is an effort to indicate now the future consequences of present public-policy decisions, to anticipate future problems, and to begin the design of alternative solutions so that our society has more options and can make a moral choice, rather than be constrained, as is so often the case when problems descend upon us unnoticed and demand an immediate response.[4]

The creation of an institute to study the future will not be enough. Our national commitment to the future cannot be restricted to a specialized body of experts doing research in isolation. The results of their work must be communicated and used by political decision-makers and their advisers. But that is still only a start. Emmanuel Mesthene argues, for instance, that modern decision-making on the impact of technology on society "runs counter to that element of traditional democratic theory that places high value on direct participation in the political processes and generates . . . discontent" and he contends that the "elaboration of a new democratic ethos and of new democratic processes more adequate to the realities of modern society will emerge as perhaps the major intellectual and political challenge of our time".[5]

Our commitment to the future requires a collective involvement. Technocratic planning from top to bottom will not work in affluent societies where the average man develops a greater need for freedom and the pursuit of his own aspirations. This is the age of involvement and it is nowhere more necessary to involve people than with the future. With such a participation it will probably be easier to reach a consensus on the issues and choices of tomorrow and on the action they require today. What we need is not only participatory democracy but "anticipatory democracy".[6]

Ideally, all public and private organizations, using a common basis and perhaps even a similar methodology, should be involved in defining their respective futures in a national and international context. Moreover, our collective involvement cannot be purely intellectual, it must also be moral and action-oriented. Our national purpose should not be merely to contemplate our possible futures but to begin now to choose and build them collectively and more systematically. In other words, we must develop a grass-roots and action-oriented approach if we want not only to predict but also to control

our future. Such an approach can be developed in Canada. It would require the creation of a *Commission on the Future,* widely representative of the public and the private sectors. It would not conduct any research itself. Its sole functions would be to convince as many individual organizations as possible to set up their own future-study units, to help them with background material and advice on how to do so, and to give them the opportunity to meet on a periodic basis to compare their progress and forecasts in the light of the technical studies and forecasts prepared by the Committee on the Future already recommended. A broad commission of this kind, with a relatively simple and inexpensive mission to accomplish, could be most useful, not only to anticipate but also to determine Canada's future on a collective basis. The approach is practical for a country like ours; it would also be genuinely democratic and unique. It would, in particular, greatly improve the general environment within which our national science effort has to be determined.

Since the proposed commission would be expected to involve as many private and public organizations as possible, it should be a mixed body in both structure and financing. It should be launched at a conference called for this purpose, well prepared in advance and sponsored by the Senate of Canada.

The Committee, therefore, recommends that the Senate sponsor a conference for the purpose of establishing a Commission on the Future whose responsibility would be to help as many private and public organizations as possible to forecast and build their future not only in isolation but together.

THE NATIONAL R&D EFFORT: TARGET FOR THE SEVENTIES

The proposed Committee and Commission on the Future would fill an important gap in Canada and provide a much better framework than now exists for the planning and selection of R&D activities in government, universities, and industry. The planning of R&D activities should cover a medium-term period and be accompanied by forecasts for longer intervals, a practice that is now rapidly spreading; it has been accepted in such countries as West Germany, France, Japan, and the Netherlands. In Canada, government agencies are now required to submit estimates of their projects and programs for a five-year period, but these proposals are often mere guesses and until recently at least not seriously considered by Treasury Board. For all practical purposes R&D activities and targets in the government sector are still determined from year to year. To a large extent this forces universities and indus-

try to do the same, whether they like it or not. Our Committee has received representations about this unsatisfactory state of affairs from both these sectors and from government research agencies.

If a medium-term plan for the national science effort and the government science budget were implemented, the overall R&D budget would not be reduced on financial grounds during that period except in extraordinary circumstances. Medium-term planning does not mean, however, that government R&D activities and programs would not be submitted to an annual technical review and appraisal to see if they should be continued, expanded, or abandoned. Existing procedures for such technical audits and assessments must in fact be substantially improved to provide a more systematic appraisal not only of the expenditures involved but also of the benefits resulting from R&D activities. The planning, programming, and budgeting system can be better adapted than it is at present to the evaluation and analysis of mission-oriented activities, although it may take several years before a satisfactory approach can be developed.[7] Unless the government is better able to determine what results from expenditures of public funds for science and technology, it will be remiss in its duty to the people who provide the funds, the taxpayers of the country, and it will not be doing a service to the scientists and technologists.

The Committee, therefore, recommends that the Canadian government and Parliament adopt an overall plan for the Seventies for science and technology, based on longer-term projections and overall national R&D targets, and that the procedures and organization of the planning, programming, and budgeting system be improved to provide a better assessment of the output of R&D activities and a better basis for determining annual appropriations for the financing of such activities. We also recommend that by 1980 the approach be formalized in a framework of successive five-year plans.

A CANADIAN INFORMATION NETWORK

We have pointed out that the results of R&D are an international pool accessible to any country to a degree varying with the type of activity involved. When these results are fully available, it is an obvious waste of effort—and an impossibility on anything but a small scale—to duplicate the R&D activities that produced them. There is no point in attempting to repeat a scientific discovery or to develop an innovation that has already been introduced elsewhere. It may be desirable to duplicate R&D activities being carried out

elsewhere if there is a chance of obtaining better results or getting results more rapidly but such duplication must be conscious and justified.

All these considerations point out the need for a good scientific and technological information network on R&D activities going on at home and abroad.

Researchers and engineers must know what is going on in their disciplines before selecting and carrying out their projects. Users of research can sponsor only a very small fraction of what they need and must rely on other sources. Private and public administrators and managers require the same knowledge before deciding their science and technology strategy and selecting the programs and projects deserving their support. An efficient information network, in short, is an indispensable tool for the formulation of a coherent and realistic science policy, as the OECD has pointed out. Regarding the *national* level, the OECD Scientific and Technical Information Policy Committee considers that:

> . . . the rapid developments of the new information technology to greatly differing extents in different countries adds a new dimension of urgency: the need is for action *now. There is therefore an urgent need for every Member country to establish, as an integral part of its science policy mechanism, a focal point for information policy issue in science and technology.* . . . It should be concerned with ensuring the most effective use of the existing information services and the development of the technical ability to use and contribute to the large comprehensive information systems which are evolving internationally.[8] [Emphasis added]

Further, the ministers responsible for science in the OECD countries agreed that each country should establish a "single high level focus concerned with all national activity" in the STI field. The Committee is in full agreement with the importance of this matter and was pleased to note in the first report of the OECD Information Policy Group—a review of Canada's STI policy —the following remark:

> Canada is probably the country in which the bases for an STI policy and for the implementation of such a policy have been studied in greatest depth. The examiners have found the work of Mr. J. P. Tyas and his team of immense value and consider that they should be warmly congratulated for completing in a relatively short space of time the study published by the Science Council . . .[9]

The Science Council did not accept the recommendations of the Tyas Group and the OECD STI Examiners Report strongly suggested that this decision was a step backward. They commented:

> The examiners are of the opinion that the recommendations of the Tyas Group deserve reappraisal and incorporation into plans for the future.[10]

The OECD report on STI policy in Canada is essential reading for anyone wishing to understand the importance of STI systems and to find a new perspective on the confusion resulting from "policy by accident" and the lack of direction caused by a "gap at the top" of the decision-making tree. For example, the OECD examiners report that although Canada "possesses numerous STI facilities which many industrialized countries might envy" these pieces of a STI system:

> . . . have however developed piecemeal, without liaison between them, without plan, without co-ordination, in a somewhat haphazard fashion. Present scientific and technical information policy in Canada may be said to be the result rather than the cause of the many information activities which have sprung up . . . It is doubtful whether the economy of the country could bear much longer the increased expenditure resulting from an expansion of the present system . . .[11]

Since the OECD review of Canada's STI policy, a Ministry of State for Science and Technology has been established. The Committee's recommendations on its role in clearing up the confusion and correcting the deficiencies catalogued in the OECD study are in Chapter 17.

An essential function of a good scientific and technical information system should be to keep a *national inventory of current R&D* programs and projects in Canada. During the hearings of the Senate Committee, we asked many witnesses whether or not such a record existed. The answer was invariably "No". Some witnesses, particularly academics, indicated that in their judgment, it would be impossible to establish such an inventory and if one were established, it would be meaningless. Some witnesses estimated the number of projects going forward at any given time; 500,000 was one example. The Committee would be the first to agree that the establishment of a meaningful inventory of research projects would not be an easy task, but somehow we must discover what the government's annual budget for science activities (approaching $800 million in 1971-72, of which close to $600 million are devoted to R&D) is being used for. In short, we must know what we are doing now so as to establish benchmarks for the future and to see whether current expenditures are justified in terms of the national priorities imposed on us by the limitations of money, manpower, and physical resources of materials and equipment.

It will be necessary to establish definite criteria of selection for research projects. This should not be an impossible task by any means, even though in multi-disciplinary problems great care must be exercised in establishing the parameters of the project in each discipline. Eventually, by the use of

computers and modern information retrieval systems, some say it should even be possible to establish mathematical models of scientific research projects that receive public or private funds. The experience gained by the Belgian government in building up an inventory of such data and by the National Science Foundation in the United States should be carefully examined.

Having once established a national inventory, the next step in a rational approach to the use of public funds for R&D would be the establishment of a national science audit directly linked with the STI system. In other words, we need machinery to evaluate and measure the productivity of publicly supported research projects. This is particularly true in the field of mission-oriented research and development. The question to be answered is: What are we as a nation getting out of the expenditure of public funds?

The Committee recognizes that in basic science or fundamental research, there must be freedom to explore new avenues, many of which may turn out to be unproductive. But in the United States, the Soviet Union, and several other countries, audits in this sector are being done, for example, by the use of citation indexes to compare the productivity of scientists and laboratories, to evaluate performance, and to prepare progress reports.

The Committee recommends that the Ministry of State for Science and Technology be made responsible for keeping a national R&D inventory and be made responsible for developing a national audit of current R&D programs and projects being supported by public funds.

The need for such an information service is obvious, and yet it was only in 1969 that the Canadian government decided, on the basis of a recommendation of the Science Council, to be formally responsible for setting up such facilities. Of course, the National Science Library existed before, and various federal agencies were maintaining embryonic services of their own, but no attempt had been made to establish an integrated and comprehensive system. The Committee is of the view that the new facilities are not adequate in scope and that they cannot be really efficient or effective because they are not properly located in the government structure. Our proposal would require more expenditure but we feel that the new system should recover most of its costs from its users.

OVERALL TARGETS FOR AGGREGATE R&D EXPENDITURES

Fundamental research, and to a lesser extent social R&D when sponsored by government, constitute an international pool that is by and large freely

available. On the other hand, industrial R&D leading to market-oriented innovations is part of the international scientific and technological race designed for the progress of domestic industries and the conquest of world markets. It is in this dual international context that a nation should determine the magnitude of its indigenous science effort; once this has been accepted, it is clear that no country can afford to conduct all the R&D activities that it needs or to remain completely out of the international pool and race.

The best that most developing countries can do is to maintain the ability to absorb as quickly as possible whatever foreign knowledge, inventions, and innovations seem useful. On the other hand, the big powers must make the largest contribution to the international pool of knowledge while trying to maintain their lead in the scientific and technological race. Speaking before the American Physical Society in 1967, Dr. Donald Hornig, who was then Science Advisor to President Johnson, said, "We accept as the goal that America must be second to none in most of the significant fields of science",[12] and then went on to say that the same determination affected the strategic sectors of applied sciences and technologies. It is not too difficult to determine what this goal requires. The Americans should be able to achieve it if they are prepared to spend a higher percentage of their GNP on R&D than other countries and to minimize waste and inefficiency. (They will, however, probably have to go through several radical changes of policy direction. At a recent U.S. seminar on the future role of technology, for instance, economist Paul Samuelson, the Nobel prize winner, warned that while the U.S. had been devoting its engineering resources to "high" technology, its competitors had been focusing on "useful" technology with the result that U.S. industry was suddenly unable to compete in technology-based products in the field of textiles and consumer electronics.[13] Another economist, Lester C. Thurow, noted that the civilian problems being given public priority tended to require "low" technology (e.g. doing what had been done before but more cheaply). Professor Thurow declared: "There is nothing conceivable in the future [U.S.] economy with such a high demand for engineering per dollar of product as defence and space."[14]).

Other advanced countries, such as Japan, the Netherlands, and Canada, are somewhere between the extreme positions of the developing nations and the United States. That is precisely where it is difficult to determine the proper level of R&D and to make scientific choices. These advanced nations cannot be content with maintaining a broad scientific and technological capability merely to profit from the international pool of knowledge and to imitate innovations introduced by others. They certainly cannot if they want to meet their international obligations, to promote their growth, and to avoid

being the victims of a widening technological gap. Japan has learned that lesson in recent years. But even with an intense R&D effort, they cannot expect to lead in the most significant fields of science and technology, at least not for long. For them, the international scientific and technological race can be envisaged as a vast competitive game not unlike what goes on in the market place in industry, and the world's pool of free knowledge as a vast community chest to which they must contribute. It is this analogy with industry, in fact, that seems to have suggested the present method of comparing countries' R&D efforts, and thus of setting levels of performance. Dr. Augustus B. Kinzel has this to say about industrial practice in his Noranda lecture at Expo '67:

> "How much research does a business require?" This is a difficult question to answer, but I do have a broad guideline. It cannot do much less than its best competitor. If it does, it will be beaten along the way and become second rate. That is not to say that it should do more than its best competitor. If it did that a continuous cycle would start with each of the competitors having to outdo the other. The amount of research done by any corporation is generally in line with that done by the industry of which it is a part . . . . The important thing to note, however, is that the companies that grow within a given industry vary less than one half of a per cent from the other good companies within that industry.[15]

This statement reflects the prevailing view in industry. It was repeated in substance to the Committee by the representatives of several Canadian firms. We also learned that it is customary for many private companies to measure their R&D effort as a percentage of their annual sales or turnover. Dr. Max Tishler, formerly first vice-president (research), Merck Frosst Laboratories, stated at our hearings that "about 9 per cent of our total sales is going into research and development"[16] and Mr. V. O. Marquez, president of Northern Electric Company, said, "As a percentage of our total company sales [our R&D has] been running at a three year average of about 3½ per cent."[17] Professor William Leonard has recently commented: "Evidence indicates that industrial managers relate their R&D budgets to sales and that, in the short run, these budgets bear a rather constant relation to sales."[18] This means of determining R&D expenditures was first suggested theoretically by John W. Kendrick who proposed it as the best indirect measure of innovative industrial activity, having found a positive correlation between changes in this ratio and rates of change of total factor productivity.[19]

At the instigation of OECD experts, drawing the analogy between nations and industries, governments have been measuring their countries' R&D effort as a percentage of the gross national product and are using this ratio

for purposes of international comparisons to see where their nations stand in the international scientific and technological contest. It is quite clear that such simple measurements and comparisons cannot give the whole story and tell exactly how a given country is doing in that race. The composition or distribution of the national effort and its effectiveness in bringing tangible results are also important factors that must be taken into account in appraising its adequacy. However, as a first approximation, we feel that these overall comparisons may have as much significance at the national level as R&D intensities have at the level of individual firms in industry.

Some might argue that Canada is in a unique situation because it has attained a high GNP per capita without expending funds on R&D to the same level as other countries such as the Netherlands and Japan. In view of the rapid rate of depletion of world resources, however, it seems a bad policy in the long run for Canada to rely so heavily on its resources for growth. Canadians should promote a much larger flow of technological innovations in the '70s and therefore spend much more on industrial R&D if they want to sustain their economy, while keeping more of their resources for the future. (*See also Chapter 15.*)

For many decades the United States has been the undisputed scientific and technological leader of the world and is likely to maintain that lead for the foreseeable future. Recently, it has contributed about half of the $50 billion that is devoted annually by all countries to R&D. This does not mean, however, that less powerful nations have no place in the race. Smaller countries, like smaller firms in industry, can be quite successful on the innovation front, provided they launch huge undertakings only with great care or approach them on a co-operative basis. This means, however, that it would be unrealistic and illusory for any of the small and medium sized nations to try to surpass the intensity of the *overall* R&D effort of large powers such as the United States. Even British and German industry have found it necessary to combine their nuclear power reactor activities in a single program. As Dr. Kinzel said when speaking of industry, any attempt to challenge the largest powers would merely result in a "continuous cycle" or an endless race that the Americans would be likely to win in the end, as they did in developing computers, nuclear power reactors, and jet transport technology.

The level of R&D expenditures expressed as a percentage of GNP may be approaching saturation level in the United States; if it were it would not be surprising. Many human phenomena, especially those directly affected by technology, grow logistically. This implies an exponential rise in the initial phase, followed by a more stable period; it is generally described by an

S-curve. Dr. J. Lukasiewicz had this to say about the American R&D effort in 1969:

> From 1920 to 1958, the U.S. expenditures on R&D have been growing exponentially with a doubling period of 4.5 years [see chart 12], whereas the GNP (Gross National Product) has been doubling, since 1950, every fourteen years. Extrapolation of these growth rates would allow the GNP being completely swamped by the R&D activities in about 1995—a rather unlikely prediction. In fact, the data indicate that, contrary to what is generally supposed, the growth of the R&D expenditures has been declining since 1958, the year following the launching of the first artificial satellite. Surprisingly even the massive space and arms programs have not arrested the decline.[20]

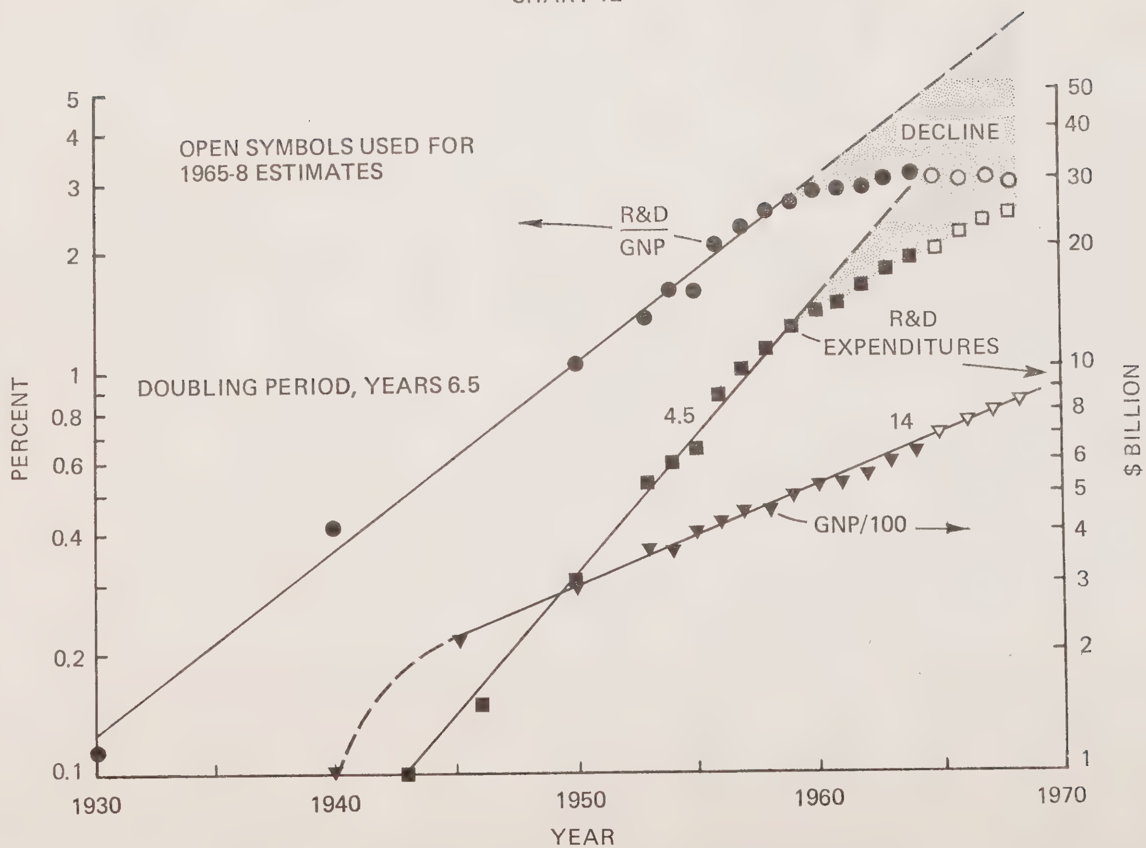
This appears to be the long-term prospect. Short-term, the U.S. government's interest in the funding of industrial R&D has warmed up again. The average annual growth of federal R&D expenditure was 22 per cent in the 1956-64 period but only 2 per cent in the 1964-70 period.[21] The decline now appears to have stopped, however, and an annual average increase of 4½ per cent is projected from 1970 to 1972.[22]

The updated version of another graph presented in Dr. Lukasiewicz's paper (chart 13) shows developments since 1930 with a logistic curve superimposed. As Dr. Lukasiewicz pointed out, the ratio of R&D expenditures to Gross National Product closely followed a logistic curve until 1964. That curve has a saturation limit of 4 per cent. Whether R&D really reached saturation in the second half of the 1960s at 3 per cent of GNP, as it appeared until the recent renewal of federal interest, or whether the lag in the late '60s was simply a wobble in a curve that is still headed for 4 per cent remains to be seen. A "surprise-free" scenario would indicate the ratio of 4 per cent of GNP as the ultimate target for the other advanced countries of the West and Japan, although this does not necessarily mean they will ever have to attain it.

Meanwhile, however, the smaller advanced nations feel that they have a lot of catching up to do. As we showed in Chapter 6 (Volume 1), by 1967 leading nations in Western Europe had already surpassed the ratio of 2 per cent of GNP, and they will no doubt reach 3 per cent by 1980. In smaller countries, such as Belgium and the Netherlands, the rate of increase in R&D expenditures will be at least twice as high as the growth rate of GNP during the next few years. Japan's ratio was 1.8 per cent in 1969 and its goal was to reach 2.5 per cent early in the 1970s.

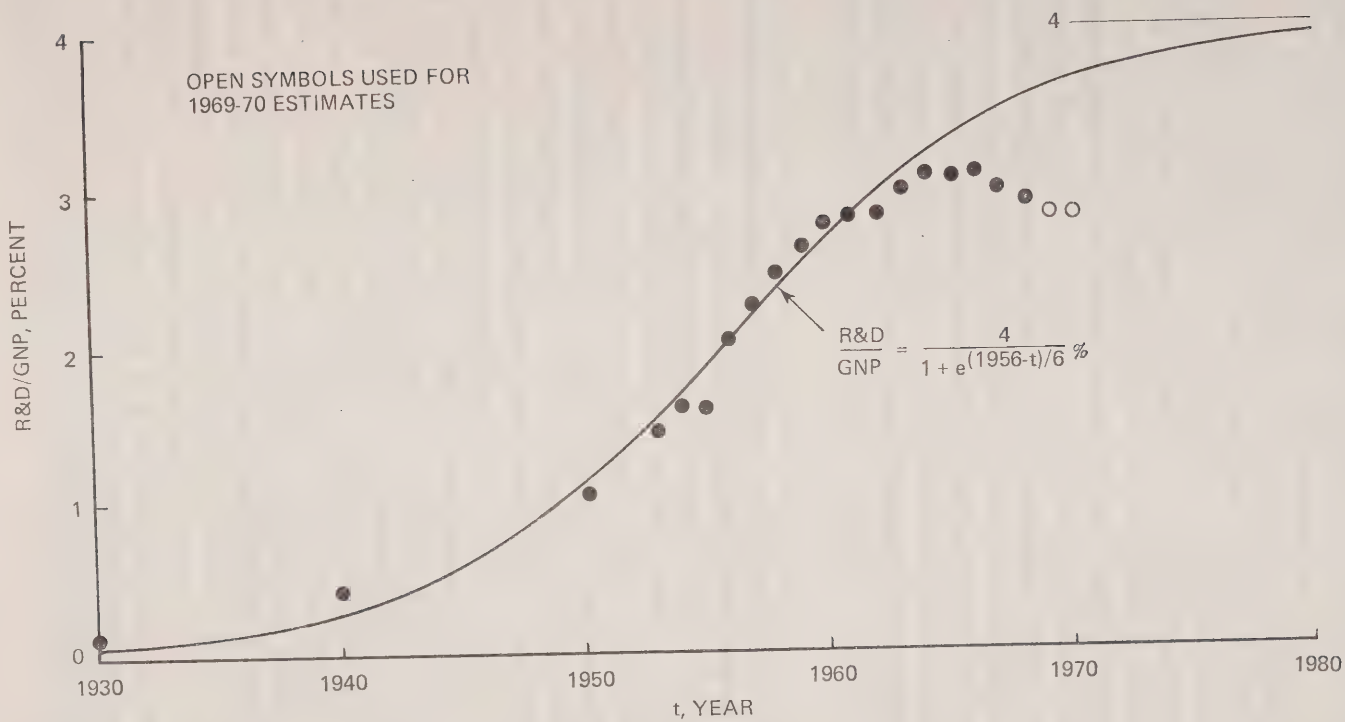
We note that in 1969 Canada's gross expenditure for R&D had reached only 1.3 per cent of its GNP. Given the situation in other industrialized countries and their targets for the early 1970s, it is evident that our country is already lagging and that this gap will widen further in the 1970s if steps are

CHART 12



GROWTH OF R&D EXPENDITURES, GNP AND R&D/GNP RATIO FOR THE UNITED STATES

CHART 13



R&D/GNP RATIO FOR THE UNITED STATES

Typically, the growth in nature and in society follows a symmetrical logistic curve, which starts with an exponential rise and then decays to an asymptotic limit. This is the way a sunflower grows, and this is how the British and American railways have reached their maximum development (length of track) over the span of a century. It appears that the R&D activities in the U.S. have run a similar course, as shown above. From 1930 until about 1964, they have followed (in terms of GNP) a logistic curve which has a saturation limit of 4 per cent. Actually, saturation has been reached already in 1964 at the 3 per cent level, and a slight decline has set in after 1966.

SOURCE: LUKASIEWICZ, J., *Complexity and Saturation in an Environment of High Technology*, College of Engineering, Virginia Polytechnic Institute and State University, Report VP1-E-70-21, December 1970.

not immediately taken to increase our speed. If we apply Dr. Kinzel's warning to our national situation, we must conclude that our country "cannot do much less than its best competitor, because if it does, it will be in trouble; it will be beaten along the way and become second rate".

On the basis of this experienced advice and of the short-term targets already set in other advanced countries, and in view of our demonstrated needs the Canadian goal ought to be 3 per cent of GNP by the end of the 1970s. This objective, however, would be unrealistic. As we have already seen R&D expenditures are of such a nature that they cannot usefully be increased too rapidly. It takes time to prepare good research programs and train the required manpower. The Committee believes this target of 3 per cent should be set for 1985 and approached by stages. Thus, we consider that 2.5 per cent of our gross national product should be devoted to national research and development expenditures by 1980, and we suggest that one of the first tasks of the Canadian Government should be to set an R&D target for 1975 that can be regarded as a practicable stepping stone to the 1980 target.

Some people will argue that the figures proposed are too large because of the requirements of more urgent programs and because the rapid rise required in the 1970s to meet the target would be unrealistic when so little of the federal budget in the 1970s can be directed toward new initiatives. To the extent that this is true, it further reinforces the need for an overall policy making machinery. To others the target will seem too restrictive. Indeed several OECD countries will reach 2.5 per cent of their GNP in the first part of the 1970s and 3 per cent by 1980. The Committee's proposal, then, will still leave Canada behind several other advanced countries.

In our view the rise in R&D expenditures involved in reaching 2.5 per cent by 1980 is impressive enough; properly allocated it would go a long way toward filling the gap between Canada and other advanced countries. Indeed, all the representations made to the Committee convince us that the proposed target is not exaggerated. There was a general consensus that Canada's effort in fundamental research was too large *in relative terms,* but nobody suggested the amount of money devoted to this purpose should be reduced. Instead it was proposed that a proper balance could be reached by increasing activities in the sectors of applied research, development, and innovation. While a greater concentration on these sectors is more likely to yield the greatest tangible benefits, it is also much more expensive, as was shown in the preceding chapter. This desirable re-orientation of the national effort will be much more costly than if Canada had to devote a greater share of its R&D activities to basic research. For this reason, the Committee

believes that its proposal is realistic. It will require a rapid rise in aggregate expenditures but if these can be effectively distributed they will yield much more by way of economic and social benefits.

The Committee wishes to emphasize, however, that its proposed target should at present be interpreted as a maximum objective to be achieved *only* if enough worthwhile programs and projects can be implemented. The additional effort should not be wasted on useless activities with no relation to public needs and priorities, such as large technological ventures selected purely under the influence of false notions of national prestige (what has been called "romantic technology") or because of the technological imperative, " 'can' means 'must'." But if we did fail to meet the target because of a lack of useful programs that should be a cause for national concern, in view of what other industrialized nations are already doing in this respect. In the perspective of the new technology and its impact on growth and the quality of life, Canada will seriously suffer if it lags too far behind in the international scientific and technological competition, which will intensify during the present decade. In summary, then:

The Committee recommends that national expenditure on R&D should reach 2.5 per cent of GNP by 1980, it being understood that the Canadian government's direct contribution to reaching this target will be restricted to the support of worthwhile programs and projects.

What are the funding implications of a target of 2.5 per cent of GNP for national expenditure on R&D? Expenditure for 1969-70 was approximately one billion dollars, divided up by sector of performance and source of funding as shown in the following table:

Table 15—Estimated Total Expenditures on R&D in Canada, 1969

	Sector of performance			
Source of funds	Business enterprise	General government	Higher education and private non-profit	Total, sources of funds
	(millions of dollars)			
Business enterprise	312	3	1	316
General government	56	359	241	656
Private non-profit	—	—	9	9
Higher education	—	—	52	52
Foreign	19	3	2	24
Total, performers	387	365	305	1,057

SOURCE: Statistics Canada, July 1971; advance information.

Canada's GNP in 1970 was $84,468 million.[23] According to OECD estimates the projected real annual growth rate of Canada's GNP for the period 1970-80 is 5.4 per cent,[24] which gives a 1980 GNP of $150 billion in 1970 dollars; with an intermediate estimate of 3 per cent price inflation per year, about $190 billion in current dollars. This implies a national R&D expenditure of $4.75 billion; in order to meet it, expenditures on R&D must grow at a compound rate of about 15 per cent per year over the period. This is about the same as the growth rate of the period 1963-69.

It is impossible at this stage to indicate even approximately what the proposed national target would mean in terms of additional public expenditures. The Canadian government's share in the financing greatly varies with the main R&D sectors and thus depends to a large extent on the distribution of the national science effort. It is also related to other factors including, for instance, the nature of the incentives used to promote R&D activities in industry. A monopoly or patent legislation specifically designed to encourage innovation does not involve any direct public spending and yet it may induce more industrial research than a generous system of grants. Loans and equity capital provided to new successful ventures are much less costly than subsidies.

If the federal government's share of the financing were to remain the same in the 1970s as it has been in the recent past, it would have to spend approximately $2,400 million in 1980, compared with about $650 million in 1969. Several recommendations later in this report will, however, reduce the share of government financing of R&D activities. The Committee believes, therefore, that the public financing required by the proposed national target for R&D is within the capacity of the Canadian government.

It is sometimes argued that no long-term goals should be set at all, because no one is wise enough to establish them. Obviously the Committee does not accept this point of view. Our view is based on the fact that, as our manpower and financial resources are limited and the number of possible R&D programs are almost unlimited, choices have to be made. And, as Derek J. de Solla Price argues, "It is anarchical to decide such issues by merely letting ourselves be ruled by the loudest voices."[25] The Committee claimed in its first volume that Canada needed a coherent overall science policy. The only systematic way for the decision-making machinery to develop such a policy is to begin with a set of long-term targets or guidelines determined on the most rational basis possible. It is only in this context that an organizational "learning process" can occur.

We must also point out that long-term objectives are not immutable. This is implied by earlier uses of the word *goal* itself. At the very beginning of the modern scientific revolution we find *goal* to mean "the object of effort or ambition, or the destination of a (difficult) journey."[26] The ancient Greeks called chance *stochos,* that is, the goal or target to be reached.[27] The probability that goals can be met or that they will remain the same over time is certainly not 100 per cent, and until recently no one supposed that it was, or that it was meant to be. The Committee has embraced this concept in urging that the goal of spending 2.5 per cent of GNP on R&D must depend on the development of projects and programs worthy of support.

The future is not surprise-free. Many events could seriously affect the proposed long-term target. The Committee's stance is that the overall objective it recommends might well have to be changed—either upward or downward—and that there must be a central policy-making machinery that has, among other things, the responsibility for adjusting and revising the goal in the light of chance events and changing circumstances. For two reasons, therefore, we regard it as necessary to set targets and create the policy-making machinery responsible for a coherent overall science policy: (1) to develop the perceptions and skills required by effective planning, and (2) to revise the path and the pace of action required by the initial goal in the face of unforeseen events that will inevitably occur in the future. In this context, science policy targets and decisions will be responsive to chance but they will not be solely determined by it; they will also be shaped by overall public purpose based on rational national requirements and international conditions.

Urging a new constitution for the United States two hundred years ago, one of the authors of the *Federalist* papers stated: "The system, though it may not be perfect in every part, is upon the whole a good one, is the best that the present views and circumstances of the country will permit," and pointed to the built-in provision for change.[28] Our position is in some ways similar. Imperfect as long-term targets and the central machinery to obtain them may be, the Committee considers them essential, to show that the decision-making process of the government is capable of determining science policy objectives, as the authors of the *Federalist* papers hoped to see their country's objectives determined, "from reflection and choice," rather than by "accident and force."[29]

The Committee believes that "reflection and choice" are required by the public interest. No one supposes the task is easy; for example an astute observer, Caryl P. Haskins, when president of the Carnegie Institution wrote:

> It will surely require at least a decade of hard work even to approach the general task of developing a more cohesive strategy for research and develop-

ment in the nation, and to formulate explicit policies that not only can set priorities in fields of work—itself a task of truly herculean difficulty—but also can estimate direct returns to the society from its investments in science and technology. The unknowns are stupendous at present, and may always remain so. But some of the elements essential in such a policy are discernible now.[30]

The Committee believes strongly that this challenge must be accepted and that the settings of specific long-term targets, to be achieved gradually and modified if necessary along the way, are an essential beginning.

In summary, the Committee proposes an increase in the magnitude of the overall Canadian R&D effort to place it more in line with those of similar countries. This change should be accompanied by improvements in the redistribution of the R&D effort toward the development end, from performance by government to performance by industry, and this can only be accomplished by instituting an effective framework of decision-making. With a Commission on the Future to assist in the development of an "anticipatory democracy"; a national network of information on science and technology, including a technological forecasting service; and medium-term plans for R&D activities, Canadian science policy would gain the broad perspective and dimension that it needs to make its full contribution to national goals.

NOTES AND REFERENCES

1. Alvin M. Weinberg, "Criteria for Scientific Choice", *Criteria for Scientific Development, op. cit.*, p. 29.
2. Dennis Gabor, *Innovations: Scientific Technological and Social,* Oxford University Press, 1970, p. 102.
3. Erich Jantsch, *Technological Forecasting in Perspective*, OECD, 1967.
4. Daniel Bell, "The Year 2000—The Trajectory of an Idea", *Daedalus,* Summer 1967, p. 639.
5. Harvard University Program on Technology and Society, *Fourth Annual Report, 1967-1968,* Cambridge, pp. 70-71.
6. For further comments on this concept and its implications, see Alvin Toffler, *Future Shock,* Chapter 20.
7. See W. R. Hibbard Jr., *"Materials R&D: Planning, Programming, Budgeting and Measurement", op. cit.*
8. *The OECD Observer,* No. 33, April 1968, p. 38.
9. *Review of National Scientific and Technical Information Policy, Canada,* OECD, Paris, 1971, p. 87.
10. Ibid., p. 89.
11. Ibid., p. 47.
12. Dr. Donald Hornig, address given to the American Physical Society, 1967.
13. Quoted in "Trauma by the Swimming Pool", *Technology Review,* June 1971, p. 74.
14. Quoted in "No Comfort in Economics", *Technology Review,* June 1971, p. 73.
15. Augustus B. Kinzel, "Industrial Research: Why, How, and What", *Man and His World: The Noranda Lectures, Expo '67,* University of Toronto Press, 1968, p. 136.
16. Senate Special Committee on Science Policy, *Proceedings,* No. 66, June 18, 1969, p. 7982.

17. Ibid., No. 68, June 19, 1969, p. 8119.
18. William N. Leonard, "Research and Development in Industrial Growth", *Journal of Political Economy,* March-April 1971, p. 235.
19. *Productivity Trends in the United States,* Princeton University Press, 1961, 630 pp.
20. J. Lukasiewicz, "Complexity and Saturation in an Environment of High Technology", College of Engineering, Virginia Polytechnic Institute and State University, Report VP1-E-70-21, December, 1970.
21. *Federal Funds for Research, Development and Other Scientific Activities, Volume XVIII,* Surveys of Science Resources Series, National Science Foundation, NSF 69-31, Washington, 1969.
22. National Science Foundation, 71-24, Sept. 7, 1971.
23. Bank of Canada, *Statistical Summary,* June 1971, pp. 471-472.
24. OECD, *The Growth of Output 1960-1980, Retrospect, Prospect and Problems of Policy,* December 1970, Table 23, p. 80.
25. Derek J. de Solla Price, *Science Since Babylon,* Yale University Press, paperback edition 1962, p. 123.
26. A usage of 1608. W. Little, H. W. Fowler and J. Coulson, rev. and ed. C. T. Onions, *The Shorter Oxford English Dictionary, on historical principles,* Oxford University Press, 1965.
27. Noted by Arnold Kaufman, *The Science of Decision Making,* McGraw Hill, New York, (translated from the French), 1968, p. 123.
28. Quoted by John R. Platt, *The Steps to Man,* Wiley, New York, 1966, p. 115.
29. Ibid., p. 111.
30. Caryl P. Haskins, "Science and Policy for a New Decade", *Foreign Affairs,* Vol. 49, No. 2, January 1971, p. 265.

14

TARGETS AND STRATEGIES FOR BASIC RESEARCH

Nine main considerations have helped to shape this chapter and its recommendations:

1. Basic research is responsible for the very life and progress of science.
2. The rate of increase of basic research activity in Canada during the 1960s was one of the highest in the world. As a result, this country is now spending a higher proportion of its R&D budget on basic research than many other advanced countries.
3. We must now enter a period of transition toward maturity in which emphasis is placed on *quality* rather than *quantity*.
4. We must not be hypocritical about the motives for our curiosity-oriented basic research activities. The goal—the development of science itself—should be clearly realized. It should not be necessary to put forward proposals for such work under the cloak of an extrinsic pragmatic goal.
5. Excellent or promising basic scientists in Canada must be strongly supported.
6. Although basic research contains its own intrinsic justification, science policy should ensure a more intimate coupling between its results and the inputs of other R&D activities.
7. Experience shows the advantage of having basic researchers from various fields working together so as to encourage multidisciplinary activities.
8. The universities that train young scientists in "the art of scientific investigation" must engage in research to give their graduates a

proper training; this research should be described as education-oriented research. It is not aimed primarily at extending the body of scientific knowledge.

9. The surplus of graduates in the basic sciences has already been noted in Volume 1. Creative research is "a young man's game" and this surplus should provide the opportunity for research laboratories in Canada, especially those with a basic-research orientation, to rejuvenate themselves.

In the last chapter we set a general target for gross expenditures on research and development (GERD) and indicated the government budget for science and technology. The next major task of science policy is to allocate these funds among basic research and the other R&D activities. Once specific targets have been accepted, special strategies must then be developed for their achievement. Responsibility for reaching the targets must be distributed among the major sectors of funding and performance—the public sector, universities, and industry. Ultimately, individual programs and projects that constitute the content or end product of science policy must be selected, initiated, monitored, and evaluated in the light of their own requirements and of national needs and capabilities.

The allocation of resources to various purposes and sectors raises conceptual difficulties because the boundaries separating these major components cannot always be clearly defined and their inter-relationships are complex. The sectors of performance are easy to identify, but they are rarely restricted to a specific type of R&D activity. For example, although universities are usually associated with basic research, this activity is also conducted in industrial laboratories; the most notable example is the Bell Labs, where two scientists have won the Nobel prize for physics. Overlapping between types of R&D activities and sectors of performance is bound to develop in a decentralized system; it can be resolved satisfactorily only when individual programs and projects are considered by a central department with a detached overview of the total picture and enough authority to solve conflicts. This department should not add unnecessary complexity by being an operating agency.

The consideration of the allocation of resources to specific sectors is strongly hampered today by the lack of detailed and reliable data on the current national R&D effort and even more aggravated by the lack of any detailed evaluation of past performance. In a subsequent volume the Committee will present a specific recommendation for filling this gap.

Basic research offers a good illustration of the problem of differentiating R&D activities for the purposes of science policy.

It is sometimes important to distinguish between basic and applied research. The OECD definition of applied research is: "original investigation undertaken in order to gain new scientific or technical knowledge". The organization adds: "It is, however, directed primarily towards a specific practical aim or objective." Applied research may be conducted by a researcher trained in basic research and utilizing its methodology. What differentiates the two activities can simply be the goal of the activity, or the researcher's intent, or the kind of organization he works in.

Moreover, basic research itself is divided conceptually into two types: curiosity-oriented research and mission-oriented research. Curiosity-oriented research (sometimes called "pure" research) stands alone: mission-oriented and applied research share the common requirement of responding to a goal outside science. Now as organizations are social inventions that exist mainly to allow specific goals to be pursued, it is not surprising to find a correlation between the goals of scientific activities and the institutions within which they are embodied. The main logical division is between "pure" research and applied research; a division we noted in Chapter 12.

The purpose of curiosity-oriented research is imposed by the inner logic of the discipline and problems are chosen by the researcher ". . . on the two criteria that they are likely to be soluble and that the solutions will be relevant to current concepts in the discipline".[1] In such research the problems cannot be defined by persons outside the discipline and the solutions are usually completely restricted to the framework of abstract concepts within the discipline. This is the territory that corresponds to Polanyi's concept of the Republic of Science.

Mission-oriented basic research is less abstract and autonomous because the goal lies outside the particular scientific discipline. "The actual scientific work is still done by the methodology of basic science, but its intrinsic purpose is mediated by an extrinsic purpose. . . . The choice of extrinsic goals cannot be determined by the methodology of science."[2] The objective of mission-oriented research may, for example, be a response to the technological requirements of a practical mission, and these requirements can even indirectly nurture the field of curiosity-oriented research. Harvey Brooks claims:

> Some of the most challenging and fundamental problems of solid-state physics or molecular physics have arisen from studies which were originally suggested by technological needs.[3]

Another conceptual difficulty with curiosity-oriented research arises because this activity is subject to all the quirks of human behaviour in the researcher himself. The satisfaction of curiosity is in itself hardly enough to justify a research project. The result of such activity depends on the motive or intent linked to the curiosity as well as the researcher's ability and skills. Thus we meet again the problem of the intentions of those who work in the field of curiosity-oriented basic research.

Professor Abraham Maslow in his book, *The Psychology of Science,* shows the two different directions in which a scientist's curiosity might turn:

> . . . the scientist can be seen as relatively defensive, deficiency-motivated, and safety-need-motivated, moved largely by anxiety and behaving in such a way as to allay it. Or he can be seen as having mastered his anxieties, as coping positively with problems in order to be victorious over them . . . i.e. he can be problem-centered rather than ego-centered.[4]

The first attitude can exploit all the attributes of scientific investigation—rigor, certainty, exactness, preciseness, neatness, quantification, proof, validation, reliability, rationality, and the other " 'good', 'nice' scientific words"[5] —defensively and to avoid anxiety. As Maslow notes:

> In the extreme instance [science] can be a way of avoiding life, a kind of self-cloistering. It can become—in the hands of some people, at least—a social institution with primarily defensive, conserving functions, ordering and stabilizing rather than discovering and renewing. . . . a kind of Chinese Wall against innovation, creativeness, revolution, even against new truth itself if it is too upsetting.[6]

On the other hand the curiosity can be related to the creativity and skills required to make worthwhile additions to the advancement of knowledge.[7]

Of all these activities we see that pure research is unique in the spectrum of activities that science policy covers, in that the researchers are free from external goals and their link is with the world of science. Some argue that pure research should not be conducted separately from applied research, but there are strong opposing voices. Some argue that basic research should be the central concern of science policy because of its potential usefulness, but that is by no means guaranteed, as the British scientist Lord Rothschild recently advised his government:

> It is also sometimes said, in justification of basic research, that chance observations made during such work, and their subsequent study, may be just as important as that made during applied R&D. While there is some truth in this contention, the country's needs are not so trivial as to be left to the mercies of a form of scientific roulette, with many more than the conventional 37 numbers on which the ball may land.[8]

From all this we see that care must be taken to ensure that the organizations in which basic research is conducted provide an environment appropriate to the activity. Such considerations have helped the Committee form some of its recommendations in this chapter.

THE EINSTEINS AND "NORMAL SCIENCE"

We do not want to leave the impression that genuine scientific progress is limited to the great breakthroughs associated with the best known names of the scientific world. These major breakthroughs, of course, offer the greatest potential for the extension of the frontier of knowledge, but they are relatively rare events. According to the physicist and historian of science Thomas S. Kuhn in his book *The Structure of Scientific Revolutions,*[9] a scientist comes along from time to time and puts forward a revolutionary new way of viewing man or his world, as Aristotle did, or as Ptolemy, Newton, and Einstein did. The revolutionary views of such scientists are called "paradigms" by Kuhn. They have, he says, always shared two essential characteristics: "Their achievement was sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity. Simultaneously, it was sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve."[10] Revolutionary scientific views come into conflict with older paradigms and usually meet deep resistance from scientists who have spent their career in the scientific environment that prevailed before the breakthrough. The Nobel physicist Max Planck noted in his *Scientific Autobiography*: ". . . a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it."[11] The same phenomenon exists in the social sciences, as Nobel Prize winner Paul Samuelson observed in his description of the Keynesian Revolution:

> The *General Theory* caught most economists under the age of 35 with the unexpected virulence of a disease first attacking and decimating an isolated tribe of south sea islanders. Economists beyond fifty turned out to be quite immune to the ailment. With time, most economists in-between began to run the fever, often without knowing or admitting their condition.[12]

Yet in any generation there are few scientists who will discover new paradigms that will redirect the subsequent course of science. Nations may never

be the home of such creative scientists and scientific revolutions. The Einsteins of the scientific world are the rare exceptions. Hence science policy should note that the community of scientists doing basic research aimed at extending science will usually be conducting what Kuhn calls "normal science". This is how he describes the three activities in which most of the scientists are engaged:

1. The determination of facts that a paradigm indicates to be of particular significance. This is important work; "From Tycho Brahe to E. O. Lawrence, some scientists have acquired great reputations, not from any novelty of their discoveries, but from the precision, reliability, and scope of the methods they developed for the redetermination of a previously known sort of fact", Kuhn comments.[13] Here is one area where scientists are concerned about the danger of the control of science in detail by politicians or other non-scientists. How could anyone from outside any particular science know which are the important facts suggested by a new paradigm?
2. Matching facts with theory. This usual but smaller class of factual determinations, Kuhn tells us, ". . . is directed to those facts that, though often without much intrinsic interest, can be compared directly with predictions from the paradigm theory".[14] Improving the agreement or finding new areas in which agreement can be reached requires constant experimental ingenuity. Kuhn notes that Atwood's machine, invented almost a century after Newton's *Principia,* gave the first unequivocal demonstration of Newton's Second Law, but "Without the *Principia* . . . measurements made with the Atwood machine would have meant nothing at all".[15] Thus this second class of normal scientific experiment rarely gives information of any intrinsic interest save its support of a paradigm or new revolutionary theory. Once again, how can laymen direct or control such activities?
3. The articulation of theory. It consists of empirical work undertaken to elaborate the paradigm theory, resolving some of its residual ambiguities, permitting the solution of problems to which it had previously only drawn attention, or establishing relationships or "laws".

Thus the basic research needed to develop and extend the insights of "normal science" often requires the forceful attention of the very best minds available. It provides absorbing excitement to basic research scientists of the highest calibre.

This description of basic research and its main components raises important science policy issues.

Research now conducted in Canadian universities and supported by federal research councils falls into several categories. It includes surveys, data gathering and analysis, especially in the social sciences and the humanities; research on the existing stock of knowledge and directly related to teaching; research responding to a specific practical mission; and basic research aimed at increasing the stock of basic knowledge. All these activities are important and should be supported. But they do not correspond to the same needs and they have different requirements. A coherent science policy has to decide whether they should be supported according to the same criteria and by the same granting institutions.

Scientific surveys and data gathering and analysis can help the process of scientific discovery and the assessment of the true nature and magnitude of practical problems. These surveys often involve the use of well established methodologies, including sampling and computer techniques, they are designed to supply specific information, and for these reasons it would appear that they should be supported and assisted by data-gathering agencies, such as Statistics Canada, or by mission-oriented government departments, which are in the best position to appraise their technical merit or their practical utility. Just as an illustration, we maintain that the national museums are better equipped to appreciate priorities and quality in the area of archeological studies than the Canada Council. To a large extent the same rule applies to applied research designed to serve a specific practical mission in the area of economic or social innovation.

Research on the existing stock of knowledge and directly related to the improvement of teaching has been downgraded and neglected in most universities, not only in Canada but elsewhere. The bias in favour of basic research and its undesirable impact on the importance and quality of teaching are condemned by an increasing number of observers. Since this bias first developed in the United States, we will quote one of its most outspoken American critics, Jacques Barzun of Columbia University. Denouncing the "epidemic cult of research", he says: "To suggest that practice, or teaching, or reflection might be preferred is blasphemy" and he claims that "Research . . . is no longer simply a vocation; it is an institution".[16]

Barzun observes the effect of this cult on the universities:

> Making the Ph.D. degree an admission ticket to teaching and research let in the seven devils of careerism; research money did the rest.

> The desire of all scholars to emulate physical science and of all universities to house none but scholars has been dearly paid for. Original work, a "contribution to knowledge" is required where there is neither talent, impulse, nor matter to make it out of . . . . Since the second world war, the desire of colleges and universities for prestige through research has become a fever, an obsession. The competition for the men, young and old, whose work is approved by the knowing is ruthless. They are offered high salaries, perquisites, and virtual freedom from teaching . . . . After the best men have been sterilized as teachers—made into drones of research—such undergraduate courses as they might have taught can always be inexpensively handled by graduate students.[17]

Other observers have been as harsh, but on the whole the criticism appears to be exaggerated—and of course it does not necessarily apply to Canada. We print it to indicate a danger to be avoided and to point out that the relationship between teaching and basic research is not as close as is often assumed.

These two activities may even be more competitive than complementary. The competitive aspect appears in the different abilities and motivations of university staff. It has been observed that a good teacher is not always an original researcher and vice versa. Moreover, a competent scientist deeply involved in a research project, as he should be to succeed, may be tempted to neglect his teaching and his students.

The primary purpose of universities is not research but, as Jerome B. Wiesner, the president of MIT, said recently, "the quest for learning, the nurture of learning, the transmission of learning, [and] the use of learning".[18] Increasing the stock of basic knowledge through new scientific discoveries will always remain a marginal contribution for any given institution as compared with the existing world pool and should be considered a secondary objective of universities. So should the training of an adequate number of students in the techniques of discovery. This does not mean that universities should not carry out curiosity-oriented basic research or be closely associated with centres of excellence in mission-oriented basic research, merely that they should not over-emphasize this role as they appear to do when they base their system of remuneration and promotion too exclusively on basic research performance and the number of articles contributed to scientific journals.

On the other hand, research directed at the existing stock of knowledge, especially at the most recent acquisitions, is absolutely essential to good teaching and the main purpose of universities, although it may not result in publications. Otherwise students will not receive the kind of training they are entitled to. With the explosion of knowledge, good teachers must master existing knowledge, as it becomes available, and should devote a great deal of their time to this important purpose. They must become proficient at syn-

thesizing knowledge in order to broaden the knowledge of their students. This is why this type of research should be much more encouraged than in the past. According to Richard B. Freeman, such support could help restore a better balance:

> If desired, the current emphasis on research in universities could be altered by changing the economic incentive to teach. The evidence of economically responsive behaviour by universities and faculty suggests that National Teaching Awards, offering the financial support and prestige to "good" teachers currently available only to researchers, would reorient university and faculty activities.[19]

The Committee suggests that teaching (including the preparation of teachers and research on the existing stock of knowledge) and basic research (including the trial period of young basic researchers) be conceived as two separate and distinct functions, to be supported according to different criteria and by different institutions.

Teaching and the training of teachers should be viewed as essential ingredients of the educational system. The same principle should apply to mission-oriented research directly related to teaching and the transfer of existing knowledge. Expenditures devoted to this type of research should be considered an important element of university and education budgets. They are aimed at the training of the total student population of which only a small proportion will become researchers. Moreover, these expenditures cannot be determined and allocated effectively by a centralized system because it is not possible to appraise from a remote base the research done by a teacher to improve his teaching. This is why these outlays should be monitored at the university or even the faculty level. Thus, this budget should be the responsibility of provincial governments in co-operation with universities. It should be noted, however, that through existing arrangements for the sharing of the cost of secondary education, the federal government would finance half of these expenditures.

On the other hand, the Canadian government would assume the financial responsibility for basic research in universities and other centres of excellence in the area. The justification for this division of labour is that this type of activity is an international obligation, indeed is Canada's major contribution to the world pool of pure knowledge. Moreover, the ability to carry out basic research must be appraised according to international standards. This corresponds to a deep feeling among the true "pure" scientists. The physicist John Ziman states:

> My impression is that the sort of scientist with which we are mainly concerned . . . —that is, more a "pure" scientist than a technologist—often feels

> no more than cupboard love for the organization for which he ostensibly works. He regards it as a convenient habitation, a source of income, a landscape within which to build his own personal, private life. No doubt such organizations are necessary, and have to be governed, but he would rather other people took on these responsibilities. Of course he wants lots of money for his apparatus and may learn to become very cunning and selfish in special pleading for it, but the major purposes for which the great corporations exist —education, defence, profitable production, national prestige—may be of little moment to him . . . .
> The fact is that the scientist gives his allegiance to the scientific community, in particular to the "Invisible College" of his specialist field of study. His true loyalty is to the informal institutions that underly and maintain the search for consensible knowledge. The true sociology of Science is . . . concerned with . . . the social interactions between a scientist and his colleagues—those other scientists studying the same problems, whether in Europe, America or Timbuctoo.[20]

The responsibility of the Canadian government for basic research in universities should cover both the direct and indirect costs, as has been recommended by the Macdonald Group. Thus universities would not be burdened in any way by the financial requirements of basic research, the pure scientist could concentrate better on his research projects because his teaching load could be substantially reduced, and the teaching staff could be increased correspondingly without any additional cost. We believe this approach represents the best way to reconcile the different requirements of good teaching and high quality basic research in universities.

Provincial governments remain completely free, of course, to initiate programs of their own for the support of additional curiosity-oriented basic research in universities.

These views should have a considerable impact on the role, objectives, and organization of federal funding of curiosity-oriented basic research. Predoctoral fellowships should be limited to graduates explicitly intending to pursue a career in basic research and showing the necessary promise of excellence. The support of scientific surveys and applied research should be assigned mainly to mission-oriented agencies. The assistance provided by the federal foundations proposed below for these purposes would be residual and available only in areas where there were no other specific federal agencies. The main task of these foundations would be the support of extramural activities and the development of a capacity, both individual and institutional, for basic research. They would be expected, however, to bear the full costs, direct and indirect, of the projects and programs they chose to support.

Changes in organization would be required. The National Research Council was conceived originally as the government's adviser on scientific and industrial research and as a foundation to support research in universities. The Committee noted in Volume 1 how in the early 1930s, the Council began to operate its own laboratories but failed to develop its advisory role. Thus, NRC became a foundation and an academy conducting intramural basic research and other types of R&D activities, but it did not operate as a council in the real sense of the word and this function was assumed by the Science Council in 1966.

The Medical Research Council emerged as an offspring of NRC and became a separate entity in 1968. Its sole function is to provide support for medical research in universities and similar institutions. The Canada Council was created in 1957 and, like MRC, carries out no intramural R&D activities. Its support covers the social sciences, the humanities, and the arts.

Neither of these institutions is a council either, because they have no advisory function. The three councils differ greatly and unjustifiably in status, composition, and role, however. The Canada Council is not an agency of the Crown and its members are chosen from the public at large. The National Research Council and the Medical Research Council are known as departmental corporations but their members are selected from among scientists. The Macdonald report indicated that the three councils differed in many other respects. The Committee feels that since they are required to fulfil basically the same functions, these differences should be eliminated.

On the whole, the Committee agrees with the main recommendations presented by the Macdonald Group. We feel that the granting function of NRC should be separated from the operation of its laboratories. In addition to the reasons given by the Macdonald report to support this suggestion, the Committee was told that NRC's board devotes about 90 per cent of its time and attention to the distribution of awards and grants, which means that the facts of life have already imposed a separation *de facto,* thus leaving NRC's laboratories without the direction Parliament thought they should have.

We also suggest that the Canada Council should be responsible only for the arts and that a new agency should be created to support the social sciences and the humanities, its members to be chosen from among social scientists and humanists. There were good reasons for establishing the Canada Council as it was in 1952: the fear of political interference if it were to be an agency of the Crown, concern about irresponsible allocation of funds if its members

did not represent the public at large. All this has since disappeared. The heterogeneity of the council members now appears a weakness. Moreover, there is an increasing difference between supporting the social sciences and the humanities on the one hand and the arts on the other.

The Committee believes that the scope of the Medical Research Council it too restricted, and this creates unnecessary difficulties when NRC is responsible for the support of all the other life sciences. Dr. E. W. R. Steacie once remarked of the teaching of the life sciences in Canada and the organization of biology:

> It seems to me that the life sciences have suffered from their domination by medicine in the East and by agriculture in the West, and that the present situation is not ideal . . . . The question is: Is the basic organization of biology wrong, and if so, is faulty organization causing harm? Though only an amateur, I suspect that the answer to both questions is yes.[21]

We believe that the present federal organization for the funding of extramural curiosity-oriented research in the life sciences is "not ideal" and that this responsibility should be assigned to a single institution.

In this new perspective, three foundations would be set up to support curiosity-oriented basic research in the physical sciences, the life sciences, and the social sciences and humanities in universities and similar institutions.

We recognize, as the Macdonald report did, that such a division is not completely satisfactory and that it does not deal with borderline cases where it is not clear where certain disciplines or multi-disciplinary research belong. The Macdonald group recommended an inter-council co-ordinating committee to resolve these difficulties. The Committee believes that these difficulties would be resolved more easily and efficiently if the three foundations, while retaining a high degree of independence, were brought together under a Canadian Research Board. This board could be composed of a president and the chairmen of the three foundations. This integration, in addition to providing an effective solution to the problem of co-ordination, would enable the foundations to have some common services, which would cut administrative costs.

We suggest that the board and foundations report to the Secretary of State. In most unitary countries the Committee visited, this responsibility is assigned to the minister of education because of the direct relations he has to maintain with universities. In Canada, the Secretary of State is already in charge of the shared program on post-secondary education and if he were

to assume this new role this would match a pattern found useful in other countries.

These suggestions and the need for greater integration of federal support in this area were underlined in the brief presented to the Committee by the Canada Council:

> Whether or not all aid to university research comes under a single Minister, the various agencies of the Government that share this responsibility will have to develop closer and closer liaison in order to ensure complementarity between services and consistency between programmes and in order to foster interdisciplinary undertakings. . . . When the recovery operation undertaken by the Canada Council is well advanced, and when the gap between the support granted to the natural and to the social sciences has been substantially reduced, various forms of government organization may well be re-examined with a view to effecting greater integration of parallel policies and to bringing all the sciences together in fuller partnership.[22]

We believe the time has now come to re-examine existing forms of organization along the lines the council suggested.

The Committee recommends, therefore:

1. That a Canadian Research Board be set up, together with three foundations, to report to the Secretary of State and to be responsible mainly for the development of a capacity for and the support of curiosity-oriented basic research in universities and similar institutions;

2. That the three foundations cover the physical sciences, the life sciences, and the social sciences and humanities, and bear the full cost, both direct and indirect, of the projects and programs they select to support in this area; and

3. That the responsibility for preparing university teachers and for supporting their research on the existing stock of knowledge designed to improve their teaching be left to provincial governments and universities within the framework of existing federal-provincial arrangements for the financing of post-secondary education.

The Committee may wish to comment further on this recommendation in a subsequent volume. We believe, however, that it represents a considerable improvement over present arrangements and a good application of the principle of the division of labour.

The features and purposes of basic research throw some light on the questions of why and to what extent individual nations should support this type of activity. The existing stock of pure knowledge constitutes an international pool freely accessible to all countries. If the quality of life is to continue to improve, the size of the pool must be extended constantly and each nation has the obligation to contribute according to its capacity. Moreover, in order to be able to benefit from this international free good, a country must maintain an indigenous research capacity. It must also sustain a mission-oriented fundamental research effort to support, when needed, its own flow of economic and social innovations.

Because of the particular features and purposes of this type of R&D activity, the big world powers have the responsibility of leading the way in deciding what contribution they will make to the international pool. Indeed, their potential is so big that whatever they do will to a large extent determine the flow of new basic knowledge. In 1967, for example, the United States was devoting 14.1 per cent of its national science effort to fundamental research and Canada was spending 23.1 per cent. But the Americans were expending about $3.1 billion for that purpose, compared with approximately $205 million in this country. The North American pool would have been enlarged by about one fiftieth if Canada had increased the basic research proportion to 30 per cent; the increase in the international pool would have been even smaller.

But how large should basic research loom in Canada by our own measures? In Chapter 6 of Volume 1 we showed that Canada followed only Japan among the advanced countries of the world in the share of science expenditure devoted to basic research.[23] This table showed that Switzerland and Britain were devoting respectively 14.5 and 11 per cent of their total effort to that activity. Although official figures were lacking, evidence available to the Committee indicated that the relative contributions of West Germany and Sweden were still lower than Britain's. It is tempting to explain these dissimilarities by attributing them to different national interpretations of the distinction between basic and applied research. However, international comparisons made on this broader basis give about the same results, as the same table showed.

The only conclusion to be derived from these comparisons is obvious: while our country lags behind most other advanced countries in the proportion of GNP that it devotes to the overall R&D effort, we contribute much

more than our "normal" *relative* share to the international pool of pure knowledge.

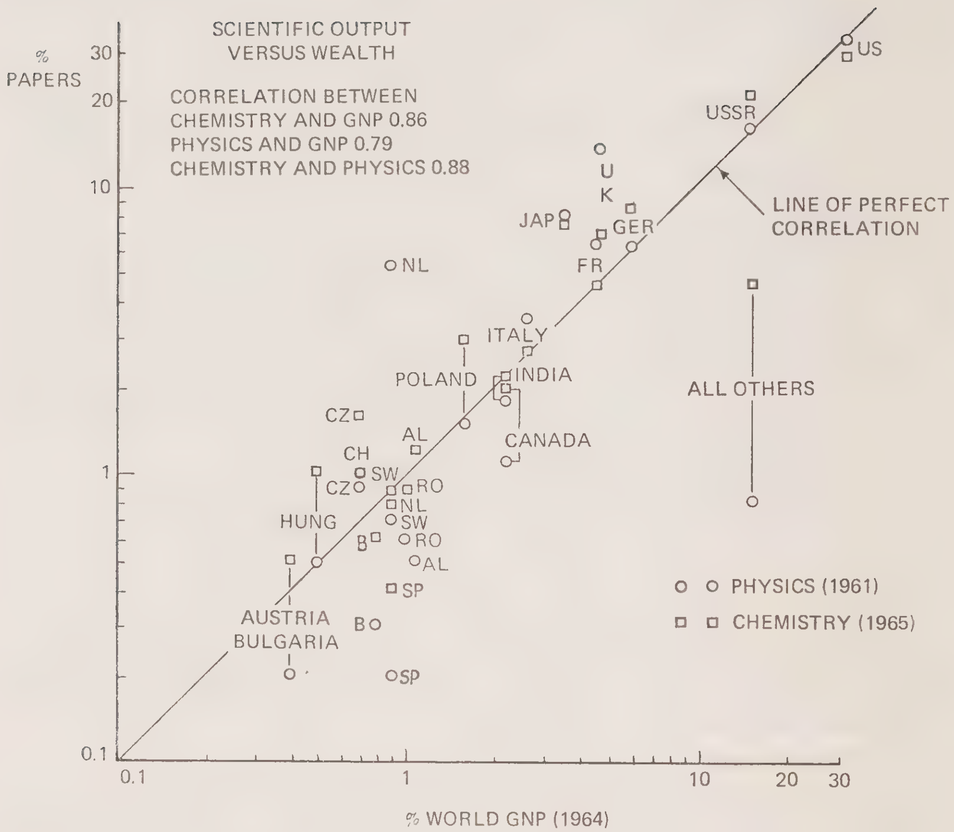
This does not necessarily mean that our effort has made significant contributions to scientific progress. On the contrary, while it may be said that in the course of the last decades we have established a solid foundation in basic science and that we have reached the level of international excellence in some sectors, the overall contribution of Canadian-born scientists residing in Canada has not been outstanding, according to the crude measurements that are available:

> The number of Nobel Prizes and other international awards received by Canadians has not been proportional to our relative financial effort. (Dr. Gerhard Herzberg's recent award is Canada's first Nobel Prize in the natural sciences.)
>
> Derek J. de Solla Price has found for most countries a close correlation between their share of published papers in the basic sciences of chemistry and physics and their proportion of the world's GNP. Price's data show, however, that Canada's share of scientific papers is lower than her contribution to the world's GNP, especially in chemistry.[24] J. Lukasiewicz has plotted these data on a graph which is reproduced on the following page (Chart 14).
>
> Canada is not even mentioned in the list of scientific discoveries in the social sciences compiled by Deutsch, Platt, and Senghaas.[25]

To the extent that these crude measurements are significant, they show that the quality of the Canadian scientific output offers opportunity for improvement. It should be noted, however, that two Nobel Prize Winners had taught in Canada before receiving their award, that some of the best known scientists in the world have come from abroad to reside in Canada, and that others are Canadians who have emigrated.

In the daily proceedings of this Committee, various government departments and agencies described, as they were requested, what they considered to be some of their success stories. A brief check was made of some of the scientific projects listed as significant and it was found by referring to the Citation Index that many of the papers referring to those projects had not been quoted subsequently by scientific investigators in other parts of the world; in fact some of the papers were referred to only by the original author in subsequent papers. This check was in no way complete, and we mention it only as an illustration of the type of evaluation that might be carried out more thoroughly by the research councils as part of their scientific audit system.

CHART 14


SCIENTIFIC OUTPUT
VERSUS WEALTH
CORRELATION BETWEEN
CHEMISTRY AND GNP 0.86
PHYSICS AND GNP 0.79
CHEMISTRY AND PHYSICS 0.88
% PAPERS
30
20
10
1
0.1
0.1
1
10
20
30
% WORLD GNP (1964)
US
USSR
UK
JAP
GER
FR
NL
ITALY
INDIA
POLAND
CANADA
CZ
AL
CH
SW
CZ
RO
NL
SW
RO
AL
HUNG
B
SP
AUSTRIA
BULGARIA
B
SP
LINE OF PERFECT
CORRELATION
ALL OTHERS
PHYSICS (1961)
CHEMISTRY (1965)

If the quality of fundamental research done in Canada has not been outstanding in international terms, that may be due mainly to bad strategy. It should not be used to justify a reduction in the financial support for this type of activity and the Committee, during its enquiry, received no proposal to that effect even from industry. Assuming that the Committee's recommendation to increase the total R&D effort to 2.5 per cent of GNP by 1980 is accepted as a desirable maximum objective, we believe Canada should adopt 0.25 per cent of the gross national product for basic research as an objective to be achieved by 1980. This figure is 10 per cent of the proposed national R&D budget, a sharp *relative* decline from current apportionment. It would be more in line with the relative contribution that other advanced countries are making to the international pool. The figure for the budget that we should devote to basic research in 1980 is about $475 million.

The Committee recommends, therefore, that approximately 10 per cent of the national R&D effort be devoted to basic research by 1980 and that an immediate start be made toward this target.

This recommendation represents a major redistribution of the Canadian R&D effort. While it still enables our country to meet its ordinary international obligations, it permits a re-orientation of effort into a pattern more compatible with our national needs and international trends. It ensures that worthwhile current undertakings will not be disrupted. It permits expenditures on basic research to be increased year by year, provided the excellence exists to justify that increased support.

It should be noted that this proposed increase must also contain a sophistication factor representing the rise in the cost of doing a given volume of research. Moreover, the Committee wants to emphasize again that this is a maximum target, which should be attained only if there are enough worthwhile people and projects deserving support. The strategy to be suggested in the next section will be based on quality and should ensure that only such projects will receive assistance.

Some scientists will no doubt argue that the proposed target for 1980 is not enough. The Committee feels, however, that it is in line with our international obligations. Furthermore, we got the impression during our hearings that many projects that have been defined as basic research had nothing to do with this activity on the definition given earlier. If these projects are eliminated from this area of support, there will be much more money left to assist genuine basic research.

A final consideration behind the Committee's recommendation is that it would like to check the normal but often undesirable trend of organizations and researchers to drift into basic research for purely prestige purposes or because a mission-oriented agency has nothing else to do. This trend has been noted by many scientists in the United States. For instance, Dr. David D. Rutstein, head of the department of preventive medicine at the Harvard Medical School, states:

> We need a better balance in our medical research program. There is so much talk about "basic research," usually undefined. Sometimes when I hear this repeated over and over it sounds as if the speaker were saying, "basic research is the research that *I* do."
>
> As a result, the reputation of clinical investigation has suffered unjustifiably, and the clinical research worker has tended to renounce his field for the more orthodox occupation of the laboratory investigator.[26]

A. M. Weinberg, the director of the Oak Ridge National Laboratory, has summed it up:

> What happens to the laboratory when the job of the agency is no longer as important as it was when the laboratory was established? If the government makes a commitment of support to its laboratories as institutions and delegates to the management the responsibility of allocating resources within the institution, it is natural that as the laboratory loses its sense of mission, the management will ensure survival of the institution by drifting into basic research. I believe that this is a phenomenon which one can see in government laboratories in many parts of the world.[27]

If government laboratories that were originally problem-oriented drift toward basic research then they have a slim chance of participating effectively in the innovation process. Moreover the Committee does not consider this rear-guard basic research as a particularly useful contribution to the development of science.

THE PRESENT STRATEGY FOR CURIOSITY-ORIENTED BASIC RESEARCH

The impression that the Committee has developed from its hearings and other sources of information is that the basic strategy followed by the federal councils in their support of curiosity-oriented basic research has been passive, quantitative, and simple. The main objective has been to try to get more money from the Treasury to raise the grants : applicants ratio. That

ratio has also been used to measure the inadequacy of funds allocated to the main scientific disciplines. This striving for an ever-increasing coverage of support may satisfy scientists but it is not very satisfactory in terms of the public interest, nor very effective in promoting scientific discoveries and excellence in genuine basic research. Within the framework of this quantitative strategy, the criterion of scientific merit is applied by peers, of course, but with diminishing qualitative returns as coverage is extended.

The Committee has two more observations to make on present strategy.

First, it appears from the evidence before us that the spending of research grants is submitted to an elaborate system of administrative controls but that *post-facto* scientific audits could be improved to ensure that the quality of past performance is taken into account when scientists seek further financial assistance for new projects.

Secondly, a brief perusal of research projects that have been supported shows that surveys and applied research tend to dominate, at least in certain areas, and that many of these projects have little relevance to the contemporary Canadian culture, economy, and society. As an illustration, we have reproduced in Appendix "1" to this chapter the list of research grants awarded by the Canada Council for the social sciences and the humanities in 1969-70. The Committee makes these observations not as a criticism of the past but as a basis for the development of a new approach in the future.

THE NEED FOR A MORE QUALITATIVE STRATEGY

A new strategy for the public support of curiosity-oriented basic research inevitably raises the complex issue of the relationship that ought to exist between society and science. The extreme arguments in this issue are between private scientific laissez-faire and public control. The growing debate on this important subject is taking place not only between scientists and politicians but also among scientists themselves. We have already touched on the subject in the first volume of this report (Chapter 10) and would now like to amplify our comments.

Many scientists feel alienated from their contemporaries. John Ziman, for example, has written quite defensively:

> . . . I feel the need to preserve the collective skills, the expert knowledge, and the delicate social organization of the scientific community from the pressures of an ignorant public, a shameless press, rapacious money-makers and opportunist politicians.[28]

More measured, but facing in the same direction, is the comment of Dr. Jacob Bronowski, director of the Council for Biology in Human Affairs at the Salk Institute:

> . . . no science is immune to the infection of politics and the corruption of power. . . .
> The time has come to consider how we might bring about a separation, as complete as possible, between Science and Government in all countries. I call this the *disestablishment of science,* in the same sense in which the churches have been disestablished and have become independent of the state.[29]

These are extreme arguments for laissez-faire. They have not gone unanswered. Anthony Wedgwood Benn, formerly the Minister of Technology in the United Kingdom, reacted strongly to Bronowski's suggestions:

> The arrogance underlying this argument is quite breathtaking. But more than that, its thinking is primitive, naive, and unscientific. . . . There is no recognition that the users of science may want and be entitled to set the targets for themselves so that their most pressing problems can receive priority and the resources to make it possible. The old and correct argument for academic freedom (which allows intellectuals to pursue truth) is extended to give to scientific intellectuals the power to take the key decisions that will shape society.[30]

In a number of countries some scientists themselves—usually the younger ones—are dissatisfied with the orientation of both government funding and science. A good example of this attitude comes in the epilogue of a collection of scientist-authored articles in *The Social Responsibility of the Scientist*:

> . . . Science is over-specialized and its approach to problems is too often atomistic instead of integrating; scientists too often want to work only with glamorous problems, ignoring the real problems of the society; and scientific societies are often polite monopolies on knowledge, effectively withholding important information from the public. . . . Because of its recent mechanistic, antihuman orientation, much of science is presently incompetent in dealing with many of the most pressing technical problems that face us.[31]

The same dissatisfaction has been expressed by young scientists in the United Kingdom:

> . . . even here [in the basic sciences] one must beware of allowing absolutely unchecked rein to even the most free of professional syndicalism, for this would still carry with it the danger of the continuance of a scientific *élite*, and, as Lancelot Hogben has put it, "no society is safe in the hands of so few clever people." It is for this reason that one must emphasize the political framework, not merely in overall budgetary allocations but in goal choice as well.[32]

As long as the debate is carried on between scientists favouring scientific laissez-faire and politicians seeking social relevance, the former can argue that the latter do not know anything about science and its requirements. But surely the same argument does not apply when the worries of politicians are echoed within the scientific community itself. And we could have quoted a number of highly respected scientists, like René Dubos, Peter Kapitza, and others, who share these fears.

Both the extreme positions in the debate are unacceptable. The politicians who would like to control and plan curiosity-oriented basic research would make the world of science moribund. The scientists like Dr. Bronowski who want science to "become independent of the state" and ask at the same time for "a single and overall fund or grant for research, to be divided by all the scientists in a country"[33] are, to say the least, illogical. Society cannot accept this purely quantitative approach.

We turn again to Alvin Weinberg:

> Society, in its support of science, assumes that science is a competent, responsible undertaking. But society is justified in asking more than this of "science as a whole". However vaguely stated, society expects science somehow to serve certain social goals outside science itself. It applies criteria from without science—broadly, criteria concerned with human values—when it assesses the proper role of "science as a whole" relative to other activities. . . .
> Internal criteria are generated within the scientific field itself and answer the question: How well is the science done? External criteria are generated outside the scientific field and answer the question: Why pursue this particular science?[34]

This is probably the only approach that can reconcile the requirements of society and science in this area of curiosity-oriented basic research. It combines two criteria: excellence, and relevance to human welfare and values. Moreover, it requires a qualitative rather than a quantitative strategy for the formulation of science policy. The criterion of excellence should be used in determining the sectors of performance, the applicants to be assisted, and the form of public support. The criterion of social relevance should be used both to allocate financial resources between the large and growing number of scientific disciplines and to select projects. We will now suggest some elements of strategy for these various areas in the light of these two criteria.

1. *Sectors of performance*

Basic science and engineering development work are two different worlds: they do not require the same personnel or the same working conditions and

their criteria to appraise performance are different. Because of the freedom it provides, the academic sector offers the best environment for fundamental research and it has the additional advantage of being the training ground for future generations of scientists and engineers qualified for advanced technology. However, some observations must be made about this particular role of the universities.

First, they must make sure that their role as performers of pure research does not come into conflict with their main teaching mission and does not prevent them from undertaking other types of R&D activities more directly related to economic and social innovations. The Committee has already indicated how this difficulty could be overcome, by reducing the teaching load of academic scientists engaged in basic research. This indicates that university authorities should be involved in the granting process and that the research councils should consult them before a grant is awarded to individual scientists.

Secondly, the Committee believes that universities should concentrate on smaller projects and programs requiring only one or two top scientists and a few assistants, which will more usually fall within one discipline than across a number. This is the kind of basic research universities are best fitted to perform, at least with their present internal organization of specialized faculties and departments. (Of course, if they can break down faculty barriers and develop successful inter-disciplinary programs, all well and good.)

Thirdly, the Committee believes that it is not necessary for all universities to be involved in curiosity-oriented research. This is not their primary function, and there are other important R&D activities available to them. Moreover, public support for this type of research must seek excellence if it is to promote the advancement of knowledge as well as the training of first class scientists. And excellence, especially in this field, exists in individual researchers before it can be developed in institutions. The Committee seriously doubts that regional disparities in this area can be eliminated or that the standards of basic research in an institution can be substantially increased through the so-called special development grants, unless they are awarded mainly to enable a university to hire and equip scientific leaders who can inspire others; as Rutherford did when he trained 14 other scientists who, like himself, won Nobel Prizes, and as Canada's new Nobelist, Herzberg, is doing in his laboratory.[35] Given the features and purposes of curiosity-oriented basic research, public financial support in this field should not be part of the fight against regional disparities. There is too high a risk of wasting money that could have been spent more usefully in depressed or remote regions on other types of R&D programs. It should never be forgotten

that the primary objective of pure research is to contribute to the expansion of the international pool of knowledge and the training of highly qualified young researchers.

We do not wish to imply that universities cannot play a role in regional development through basic research. Universities could well put together R&D teams to train people in certain problem-centred areas just as the land grant colleges in the American mid-west attracted highly skilled basic researchers to work on problems of agricultural production; the same thing has occurred in universities in the Canadian Prairies.

2. *Selection of Candidates and forms of public support*

We note three main forms of public financial support offered to scientists: scholarships to train future researchers, fellowships to enable newly trained scientists to develop and prove their ability for basic research, and grants to recognized scientists in universities and similar institutions.

Here it seems the only proper strategy is to arrive at a pyramidal distribution of the number of individuals receiving assistance.

A broad basis at the scholarship level is needed to detect potential talent. Even so, pre-doctoral scholarships should be offered by the proposed foundations only to candidates of ability who declare their firm intention of pursuing a career mainly in basic research.

Fellowship programs should be determined on a more restricted basis. The period of assistance at this stage should not be more than five years and the fellows should be associated with a university or with a mission-oriented basic research organization in government or in the private sector. This is long enough for the young scientist and his peers to see if he has the interest and capacity to do research of high quality.

While scholarships should be available for use at any university in the world, fellowships should require residence in Canada, but young scientists should have their choice of institutions in seeking the best research atmosphere available in our country.

The Medical Research Council initiated such a program of fellowships five years ago, and it appears to have produced excellent results. All the proposed foundations should set up similar schemes because these fellowships may provide the best way of developing excellence in basic research.

Finally, at the top of the pyramid there would be a small number of highly competent scientists receiving research grants.

The process of excellence can also be portrayed by a trajectory of the different stages scientists experience in their career, including the formative years, the reaching of the peak, and the declining period. John Ziman has described the first stage.

> The graduate student not only learns the advanced technique of his subject and makes some small contribution to it; he becomes acquainted with the rules of scientific communication and controversy, and acquires his own internal version of the standards of argument and proof demanded by the scholarly world.[36]

Then comes the second stage. It has been observed that "For most research workers . . . creativity reaches a peak at a relatively early age and then declines. In the physical sciences, for example, it has been suggested that the peak is normally between 30 and 35 years" and that "career structure should not be based on a life-time in research, except for those few who retain their inventiveness and become research leaders. For the majority, arrangements should be made to absorb older research workers into other areas . . . leaving room for a continuing inflow of younger researchers".[37]

There are always notable exceptions where great scientists maintain their intellectual power well beyond 40, but observers agree more and more that basic research is a young man's game. It is interesting to note that the mean age of scientists in the Siberian Section of the U.S.S.R. Academy of Sciences—the country's largest scientific centre—is only 33 years, according to the Russian science policy observer G. M. Dobrov.[38] He suggests that for the "optimum" age distribution of a laboratory the mean age should be no higher than 35-40 years. To maintain the vitality of research, observers suggest that mobility within the scientific community must be encouraged. Dobrov, noting that "The task of rejuvenating our scientific manpower is considered to be an important aim of our national science policy", points out:

> . . . to form communities of scientists that are stable and self-regulating in age there must be not only replenishment, but also the exchange of personnel with other spheres of useful activity (such as education, production, or information work). . . . The close functional relationships between scientific centres, universities and industry which have been developed in recent years help in this direction.[39]

The OECD Report on Science Policy in Canada notes:

> . . . increasing the mobility of scientific personnel between the different types of institutions is no doubt an important problem in Canada, where rigidity is much more apparent than in the United States.[40]

(While OECD is referring to mobility between the various sectors of performance, we suggest there is also a problem of mobility between basic research, other R&D activities and other types of occupations such as management, teaching, or information and scientific advice.)

These are important considerations in any strategy to develop and maintain excellence in basic research. Some comments made by Dr. Hans Selye, the director of the Institute of Experimental Medicine and Surgery at the University of Montreal, to this Committee deserve serious consideration, especially when applied to the selection of candidates in curiosity-oriented basic research:

> A question which may be pertinent and which very often arises is how one can justly distribute money to scientists in the first place. The writing of applications is not a very good indicator. At the present time, as I have tried to point out in my book, the accepted procedure, both here, in the United States and in most other nations (in France for example) is first to write an application in which you describe precisely what you want to do, what you intend to discover, how you want to do it and how much it will cost. This is examined and a decision is taken. I think that this procedure is full of loopholes and errors which ought to be pointed out.
>
> First of all, there is absolutely no relationship between the ability of a person to get a grant and his ability to solve a scientific problem. Entirely different talents are needed to sell an idea to a grant-giving body on the one hand and to solve a problem in the laboratory on the other. They have absolutely nothing to do with the other. There are people who have excellent "grantsmanship". Because they practise it all the time, they do not do any research, but they know exactly what every grant-giving body likes to hear. That is the first point.
>
> The second point is that the distribution of funds by other procedures is, it is said, very difficult, because the granting bodies say, "How are we going to subsidize somebody if he does not tell us what he wants to do with the money?" This is erroneous. You judge by past accomplishment. . . .
>
> . . . a man graduating from medical school and starting medical research cannot be judged by past accomplishments because he has not yet done any research. He has to start somewhere, but although he cannot give a report on past research, he can at least get recommendations from his former professors. Thus he can receive a small award so that he can prove himself, and the next year he will be judged on his accomplishments. Gradually he will have a few publications to show and on this basis a decision can be taken as to his merit as a scientist. There should be a special board or committee to follow the work of these young investigators. Thus, one can keep a man supplied with funds from year to year, not on the basis of what he has promised to do but on the basis of what he has actually done.

> I think it is highly unlikely that really new ideas can be subsidized by the old method, because one of the greatest fallacies of this procedure is that, if you know how to write a report on what you are going to do, stating exactly what you want to discover, then your work is not really new. By definition it is not new because if you can plan it, there are already so many precedents for what you want to work out, that yours is the logical course of action. Consequently, it is not a really original discovery. Truly original discoveries are never made that way.
>
> I doubt that Fleming could have obtained a grant for the discovery of penicillin on that basis because he could not have said, "I propose to have an accident in a culture so that it will be spoiled by a mould falling on it; and I propose to recognize the possibility of extracting an antibiotic from this mould." . . .
>
> To my mind, you can only evaluate a man's worth efficiently by taking into consideration his whole past, and particularly his immediate past, because he may have deteriorated in two ways. In time, a person may have developed into a bureaucrat or may be getting too old. But by taking into account his last two or three years, this would be a relatively just system.[41]

Two other elements of strategy should be mentioned. The Committee has already suggested that the number of scientists receiving public support should be determined according to a pyramidal distribution, with a fairly broad basis in the formative years. The degree of supervision should follow the same pattern, the amount of financial support should be a reverse pyramid. In other words, as a scientist develops real excellence, he should receive more generous support and be submitted to fewer administrative requirements. This emphasis on quality rather than quantity would substantially alter the general climate surrounding basic research in Canada. A smaller number of scientists would qualify for research grants but excellence would be more generously rewarded.

The peer system for the selection of candidates, the determination of the degree of assistance, and the appraisal of research performance should be improved. The traditional system has many critics. Hilary and Steven Rose argue that basic research should not be considered by peer groups, ". . . so that policy-making does not atrophy in the hands of the elderly representatives of middle-aged disciplines".[42] Sir Peter Medawar notes:

> In my experience [committees of scientists] are just as easily swayed as are committees of laymen by considerations of fashion and a desire to avoid making mistakes by backing only those horses that are clearly seen to be in the final straight. . . . Lay committees have at least this to be said for them: that they have the genuine and well-founded humility that grows out of a vivid awareness of their own fallibility. It is this kind of humility that committees of scientists too often lack.[43]

Even Alvin Weinberg has been moved to criticize the panel system ". . . insofar as judge, jury, plaintiff, and defendant are usually one and the same".[44] The danger is even greater in Canada, where the scientific community is small. Some scientists, for instance Hilary and Steven Rose, have suggested that the members of these panels should be elected by the scientific community. Whether or not it would work in Britain, this suggestion seems impractical in Canada.

The Committee believes, however, that members of panels should be selected with particular diligence. Scientists from related disciplines and from abroad should be included to broaden the basis of evaluation. The panels need a good knowledge not only of the applicant's potential or past performance but also of the nature and quality of the work being done elsewhere in the country and in the world. Decisions should always be taken by a secret vote to guarantee impartiality. Panel members should be properly remunerated for their work and be replaced after a specific term of service. The foundations should review their policies in the light of the Committee's suggestions. It is obvious that the responsibility for identifying the scientists who should be assisted is not within the competence of laymen. This delicate and complex role clearly belongs to competent peers—and their names should be made public so that the scientific community can, if need be, criticize bad appointments.

The Committee therefore recommends:

1. That the proposed foundations, in their efforts to develop and support excellence in curiosity-oriented research, follow a strategy emphasizing quality rather than quantity;

2. That they continue or establish programs of post-doctoral fellowships awarded for a maximum period of five years;

3. That they provide research grants only to applicants who have demonstrated international quality standards in their past performance but that excellence be more generously rewarded and subjected to less administrative control; and

4. That they improve their peer system, wherever necessary, to ensure the highest possible degree of competence and impartiality.

3. *Priorities*

We have emphasized excellence in the selection of applicants for public support in basic research, but this should not be interpreted to mean that we

think all areas and topics should be supported indiscriminately, without regard to the international scene or to particular Canadian requirements. On the contrary, it is almost equally important to establish priorities and correct imbalances between the main categories of basic research. This is where the criterion of social merit or relevance should apply.

One area of imbalance is the surplus of Ph.D.s. The OECD review of Canada's science policy said:

> If one takes into account the number of foreign students taking their doctorate, which appears quite large, together with partial information gathered from various universities, it does seem . . . that the supply of highly qualified personnel is in excess of the demand in Canada. It might be deduced from this that the expansion of the Canadian universities in recent years has been made possible mainly by recruiting foreign graduates and by supplying the United States scientific labour market.[45]

A recent Science Council of Canada study, *Prospects for Scientists and Engineers in Canada,*[46] confirms the rapidly growing surplus of Ph.D.s in the physical sciences and engineering. For several years, the study claims, the Ph.D. output from Canadian universities has grown about 23 per cent each year, which corresponds to a doubling of output in less than three and a half years. From 1968 through 1970 Canadian universities graduated about 2000 Ph.D.s in science and engineering; the 1970 Science Council survey of 60 companies (including the 30 research-intensive companies that together employ 75 per cent of all Ph.D.s in industry) indicated that over the same period the net increase in employment of Ph.D.s was 40, instead of the 210 originally estimated in 1968. By 1972, the study indicates, the annual Ph.D. output from science and engineering faculties of Canadian universities will reach 1850. At the same time job opportunities in industry are declining and the demand for Ph.D.s in the university and government sectors is quite modest.

Within this unhappy situation there are some curiously convoluted details. Industrialists say they have to import a substantial proportion of the personnel needed for industrial research. There is something wrong with federal support programs that train scientists for export while Canadian industry has to import applied scientists and engineers to meet its needs. Again, while an abnormal number of fellows in the physical sciences come from abroad to take advantage of financial assistance available in Canada, a high proportion of young Canadian social scientists use their scholarships to go abroad. Furthermore, the Canada Council has no post-doctoral fellowship program in the social sciences and the humanities, a real gap in its effort to develop excellence.

The Committee believes this whole situation represents a serious misallocation of national funds. We are surprised that these conditions have not been

perceived earlier, and worried that information about this serious manpower problem is still very inadequate. Indeed in the foreword to the Science Council study Dr. P. D. McTaggart-Cowan, executive director of the council, writes:

> Perhaps even more important are the many gaps in the supply of data needed to make the discussion objective. The existence of these gaps is a serious impediment to a proper understanding of our problems with regard to highly qualified manpower and to arriving at the best possible solution, and indeed, to placing this part of the overall manpower problem in Canada in its proper perspective.[47]

The Committee recommends that the Minister of State for Science and Technology initiate a thorough re-appraisal of all the Canadian government's scholarship and fellowship schemes in the light of the current scientific and technological manpower situation and of the likely requirements of the new orientation that the national R&D effort will take in the 1970s. This study should be conducted in close collaboration with the proposed foundations and the Department of Manpower and Immigration.

The criterion of relevance leads us to three rules for the support of specific basic research programs and projects.

First, to the extent that scientific knowledge is an international free good, the main purpose of basic research would not be served if a nation were merely to duplicate, at a lower level of quality, what is being done elsewhere. The Committee has been told repeatedly that no scientist worth his salt would knowingly and uselessly duplicate the work of his colleagues. We accept these statements and we admit also that some duplication may be useful. The foundations should make sure, though, that they do not support unconscious and useless duplication.

Secondly, Canada should not initiate alone any huge projects in basic research because they would take too big a share of our R&D effort. It is sometimes argued that our country will not be able to keep top scientists if they cannot get involved in the great scientific challenges of Big Science. This may be true. It may also be true that involvement in Big Science is even more rewarding if it encompasses international co-operation. The Committee feels that the possibility of joint projects in the field of Big Science has not been enough explored. Indeed, international collaboration in curiosity-oriented basic research should be easier to achieve than in any other R&D area. Many other countries, even big powers, feel the same limitations that Canada experiences. We suggest, therefore, that Canada should not limit her interest in other countries to the exchange of scientific

information but that she should discuss the possibility of joint programs in the area of Big Science.

Thirdly, as a general rule, priority for public support in basic research should be given to areas where applied research and development are also being done in Canada. This kind of national priority merely follows from the intelligent application of the principle of the international division of labour, and it does not conflict with our obligation to contribute to the international pool of knowledge. The scope of science is so vast that it seems unrealistic not to attach more importance to areas relevant to the Canadian scene than to others where, for various reasons, the results of basic research cannot be applied in our country.

The Committee therefore recommends that the proposed foundations, in applying the criterion of social merit, turn down research projects or programs that involve undesirable duplication of others carried out elsewhere in the country or abroad and assist only those that are relevant to the Canadian scene. We further recommend that the foundations reject Big Science projects to be carried out with Canadian support alone.

The test of social merit should also be applied to the allocation of funds among the main categories of scientific disciplines, namely, the physical sciences, the life sciences, the social sciences and the humanities. At present curiosity-oriented basic research in the physical sciences receives the most public support, the life sciences, including medicine, come second, and the social sciences and the humanities are at the bottom. This pattern is worldwide, not just Canadian.

There are various explanations for this situation. When governments began to support basic research, the physical sciences were much more advanced than the others so that the criterion of excellence applied much better to them. Moreover, the objectives of the "first generation" of science policy were mainly military and economic, and these were the sciences expected to make the greatest contribution to these goals. And the historical pattern of support has been reinforced by the incremental approach to budget-making followed in Western countries.

Most of these reasons are now losing their weight. The tremendous progress of the physical sciences in the last decades seems to have brought some avenues of exploration to at least temporary dead ends. Progress in the health and life sciences, such as molecular biology, however, has brought them to the point where new paradigms and major breakthroughs are presenting fresh opportunities for "normal science", and these sciences may

reach their golden age during the next 15 years. The situations of these two major areas have thus been reversed.

It is quite true that the social sciences and the humanities cannot rely as much on a rigorous methodology as the physical sciences and that their generalizations about phenomena cannot be as broad. But these disciplines have never been so well equipped to make major breakthroughs in basic research. It is easier to get the necessary data, and mathematical tools have been perfected to meet their needs better. The computer, sampling techniques, systems analysis, and system dynamics, most of which have been developed by engineers, are new instruments that should be most useful.

Moreover, as we develop a "second generation" of science policy aimed at improving the quality of life, the contribution of the life sciences, the social sciences, and the humanities will become increasingly important. It also seems that the results of basic research in these areas are more rapidly applied and transformed into innovations than those produced in the physical sciences. For instance, the survey made by Deutsch, Platt, and Senghaas indicates that scientific discoveries in the social sciences are transformed into innovations in 10 to 15 years, which is half the figure estimated for the physical sciences.[48] If this is so, more generous support in these areas could yield a high rate of social returns.

The incremental approach to budget making is gradually being abandoned for the distribution of total government expenditures. But it is specially urgent to replace it in the sector of science policy by more rational strategies and a coherent system of priorities. Badly needed improvements in the quality of life may depend on a better distribution of our national R&D effort.

All in all, the traditional preferential treatment accorded to the physical sciences seems no longer justified. Dr. G. Malcolm Brown, the chairman of the Medical Research Council, told the Committee that the total support devoted to medical research in the United States " . . . is higher by a factor of the order of five to seven, on a per capita basis" than in Canada.[49] The Committee feels this disproportion is too great. It appears also that the distribution of increased support in this area should be reviewed. The Committee noted, for instance, that in 1969 NRC inaugurated a special grants committee on psychology. Psychiatry, however, came under the clinical investigation committee. With the spread of diseases of the mind, we suggest that more special attention should be given to psychiatry.

In the social sciences, especially in economics, an important portion of public assistance has come from government departments and royal commis-

sions in the form of consulting contracts and commissioned studies, and this support has been more financially attractive than the grants offered by the Canada Council. Most of it, like the Council's grants, has been given for applied research and development, with the result that curiosity-oriented basic research in the social sciences has been seriously neglected. Yet it is probably in this sector of the social sciences and the humanities, including philosophy, that the needs are most urgent.

The mounting economic, social, and cultural problems that industrial nations are now facing were touched on at the end of Chapter 11. Indeed, even as advanced societies achieve affluence they still face economic stability problems. They have to learn how to improve the quality of life, and perhaps even how to be satisfied with no material growth, if the equilibrium between nature and mankind is not to be destroyed permanently. These nations, including ours, will have to face these unprecedented challenges at a time when the permanent technological revolution produced by the international R&D race will be generating a greatly accelerated rate of change, when a radical transformation of man and his environment will occur, and when a new set of acceptable values will be badly needed.

These new challenges make their impact mainly in the areas of the social sciences and the humanities. To meet them these disciplines desperately need new paradigms. The "Keynesian Revolution" occurred in the 1930s, for instance. It does not seem to fit the economic conditions of the 1970s as well. The older philosophical systems do not seem capable of providing a new set of values acceptable to affluent societies. It may well be that the new paradigms will have to come from a multi-disciplinary approach, a joint effort of the social sciences and the humanities.

We doubt, however, that these disciplines are ready for breakthroughs. We wonder if they are even ready to contribute through "normal science" to the further development and sophistication that most new paradigms require. The poor conditions of the social sciences in Canada have been deplored on several occasions, more consistently than any other part of the Canadian R&D effort.[50] They have been emphasized by the Massey Commission, the Glassco Commission, the Bladen Report on *Financing Higher Education in Canada* published in 1965, the Science Council, the Economic Council, and the Macdonald report on *The Role of the Federal Government in Support of Research in Canadian Universities*. Similar views were expressed by many groups that appeared before the Committee, including the National Research Council. The neglect has been particularly evident in the sector of basic research, which is just the reverse of the situation in the physical sciences.

Arthur Smith, when he was chairman of the Economic Council, described this major gap:

> As regards basic research, it is perhaps worth noting at least three important contrasts between the social sciences and the natural sciences. The first concerns the pitifully small amounts of financial support that have been available for basic research in the social sciences. These amounts stand in sharp contrast with the volume of support for such research in the natural sciences. . . .
>
> Second, it can be persuasively argued that it is much more important to develop *indigenous* basic research in the social sciences than in the natural sciences. Over a wide spectrum of research activities in the latter field, basic research from abroad can be imported or adapted to Canadian needs with reasonable ease. Much of the basic research in the social sciences undertaken abroad, however, has little relevance to Canadian interests and needs because it relates to environmental situations, institutional conditions, behavioural relationships, legal frameworks, and a milieu of social, economic, political and cultural structures that are different (in many cases, substantially different) from those in Canada.[51]

Before a strategy can be developed to fill this serious gap, we must note several anomalies.

In 1969-70 the Canada Council's total budget for the social sciences and the humanities was $18.2 million. About 60 per cent was given for pre-doctoral scholarships, none for post-doctoral fellowships. The universities had not foreseen the rapid increase in enrolment in the humanities and the social sciences, and the council was worried by the lack of properly trained Canadian teachers,[52] with demand being met by massive imports mostly from the United States. It may well be, however, that the council is too late in attempting to fill the gap and, in putting so much emphasis on pre-doctoral scholarships, runs the risk of producing a surplus of teachers and Ph.D.s, as Canada has done in other areas.

It must also be noted that most pre-doctoral scholars in the humanities and the social sciences go outside the country to get their Ph.D., although it would seem that most should not, particularly in those disciplines. Why have good post-graduate university centres not been developed sooner? The question is even more poignant when we note the Macdonald study's revelation that in 1967-68 approximately half the students taking their Ph.D. in the natural sciences and engineering in Canadian universities came from abroad.[53] These faculties devoted to the physical sciences appear, in fact, to be over-expanded and to accept an unduly high proportion of foreign students, at a high cost to Canadian taxpayers, to justify their existence.

In 1969-70, the Canada Council devoted only 26 per cent of its budget to research grants, as compared with 70 per cent for NRC and MRC. But its award rate, at 85 per cent, was significantly higher, and a substantial number of projects submitted to the council had nothing to do with basic research. Why do less than 10 per cent of scientists teaching the social sciences and the humanities in universities ask for Canada Council grants? Why are there so few applications in the area of curiosity-oriented basic research? Why are we losing some of our top scientists and what would they require to come back?

Another area of concern is the growing isolation and even contempt which exists between these various disciplines, at a time when multi-disciplinary effort seems to be needed to produce major breakthroughs. Harry G. Johnson, the economist, said recently before the Finance Committee of the Senate:

> I do not believe in sociology. Sociology is the last resort of second-rate economists who cannot think about the economy. . . . I do not believe in psychology.[54]

This kind of splendidly contemptuous isolation is in sharp contrast with the attitude of the mathematical economist Wassily Leontief:

> To deepen the foundation of our analytical system it will be necessary to reach unhesitatingly beyond the limits of the domain of economic phenomena as it has been staked out up to now. The pursuit of a more fundamental understanding of the process of production inevitably leads into the area of engineering sciences. To penetrate below the skin-thin surface of conventional consumption functions, it will be necessary to develop a systematic study of the structural characteristics and of the functioning of households, an area in which description and analysis of social, anthropological and demographic factors must obviously occupy the center of the stage.[55]

These various problems can be explained rather easily. Given the underdeveloped state of the social sciences, it is probably more difficult to do basic research in this area than in the natural sciences. The gathering of necessary data and "observed facts" is more time-consuming. It is also more tempting for the social scientist to do applied research and development work, especially when the remuneration is higher, because he is naturally less detached from society and more involved in the process of social change than the natural scientist. Moreover, it is easier to escape the challenge of basic research and take refuge in historical or comparative studies. Even those who dare to face it are perhaps too inclined to view the mathematical tool as a substitute for qualitative theoretical analysis and to apply it to what Leontief calls "non-observed facts".[56]

The impediments to good basic research in the social sciences and the humanities will have to be overcome primarily by the scientific community itself. But the Committee believes that it can be helped by a more appropriate strategy of public support. The new approach should contain the following elements:

1. The proposed social sciences and humanities foundation should put much less emphasis on pre-doctoral scholarships and concentrate its program at this level on applicants who appear to be able and willing to pursue a career in basic research. Other Ph.D. candidates who want to devote their time mainly to teaching or to more applied fields should get their assistance from universities, from mission-oriented government agencies, or from the private sector.
2. The above foundation should set up a generous scheme of five-year post-doctoral fellowships for young scientists attached to a university who are prepared to devote most of their time to basic research. It should also help to develop at least a few academic centres of excellence for graduate work in this area. Fellows could be useful in this, under the leadership of top scientists.
3. The above foundation should gradually get out of the fields of applied research and development when mission-oriented agencies can support them. For instance, applied archaeology and anthropology could be left to federal or provincial museums. Such a shift would enable the foundation to concentrate its grants on curiosity-oriented basic research, to support much more generously those scientists who are attaining international standards of excellence, and to encourage the development of high quality multi-disciplinary teams.
4. For the 1970s at least, the traditional allocation of Canadian government funds for curiosity-oriented basic research should be ignored and the situation of the social sciences and humanities should be treated as an emergency. Rapid progress should be aimed for.

The Committee recommends, therefore, that at least during the 1970s the order of priority in government support for curiosity-oriented basic research should be, first, the social sciences and the humanities, and second, the life sciences, mainly those related to human health, provided of course that international standards of excellence can be developed and achieved in these areas.

This recommendation represents a drastic change in priorities. However, given the targets proposed by the Committee for the national R&D effort, even this

shift would not completely stop the growth of curiosity-oriented basic research in the physical sciences in the universities. The Committee does, after all, recommend that an additional $200 million a year be devoted to the support of basic research by 1980. Moreover, the new emphasis we propose would mean a transfer of responsibilities for the support of applied research to mission-oriented agencies, which would enable the foundations to devote a greater portion of their budgets to basic research.

MISSION–ORIENTED BASIC RESEARCH

Experience shows that major advances in technology and innovation have been unduly delayed or unwisely accelerated because of the lack of basic scientific knowledge. The development of transistors and solid state circuits was retarded by the need for more basic research in solid state physics.[57] Some drugs would not have been circulated if more oriented basic research had been done on their side-effects. Policies designed to enforce certain forms of competition are based on theoretical economic models constructed more than 40 years ago and do not correspond to the conditions of the real world today. If the innovation process is to be accelerated and controlled, the skills and understanding of basic research scientists are required. This is the area of mission-oriented basic research, which works toward a goal extrinsic to science itself.

Although there have been many instances when the interests of academic scientists and the interests of scientists needing specific knowledge have coincided, it is not possible to rely exclusively on curiosity-oriented research done in universities to meet these needs, because most academic scientists want to remain as free as possible and to select their projects according to the criterion of scientific merit. It would be mere accident if a research effort based on individual curiosity and freedom solved any of the more practical problems mentioned above. At the same time only a few industrial firms, world leaders in their field, can afford to do basic research.

So the government must fill the gaps left between curiosity-oriented research and the sparse efforts of Canadian industry in this area. In addition, the government maintains applied research and development programs designed to serve its various missions and these programs too must be reinforced by basic research activities. In 1969-70 the Canadian government spent $50.8 million, or 18 per cent of its expenditures on intramural R&D activities, on basic research in its own laboratories.

This effort was heavily concentrated on the physical sciences and the life sciences not related to human health. Although no figures are available for the social sciences, it is quite certain that basic research activities carried out by the government in this area were negligible and too diffused.

The Committee believes the government effort in this area could better serve Canadian interests if it were more centralized and more balanced. This could be best achieved in a national research academy, composed, in the beginning at any rate, of three major institutes, one each for the physical sciences, the life sciences, and the social sciences.

These institutes should have a large degree of autonomy. But the fact that they would work under the same umbrella organization should prevent them from unconsciously and unnecessarily duplicating work in borderline areas and most importantly would help them to set up the multi-disciplinary programs that will become more and more desirable in mission-oriented basic research.

These institutes would be entitled to undertake some curiosity-oriented research but they would not be designed to compete with universities in this respect. Their main role would be to undertake basic research projects at the request of industry or mission-oriented government agencies on a fee basis. They would also be responsible for the organization of Canada's participation in international programs involving Big Science, which are too expensive for our country to undertake on its own. They would also have the right to contract out some of their programs or projects to universities or to industry.

This formula offers several advantages:

1. The institutes would offer a proper environment for Canadian scientists who would rather solve problems than teach or do curiosity-oriented basic research in the academic sector. It would also present an opportunity for university scientists on their sabbatical year. Scientists from the institutes could go to work in the universities in staff exchanges. This would strengthen the whole Canadian basic research effort.
2. Many of the problems facing society today are complex, require a basic understanding of the real world, and have many scientific dimensions; they need, ideally, teams of basic scientists from several disciplines to tackle them together. It is not always easy to organize such teams in universities, nor is it always advisable for the Canadian government to build multi-disciplinary research centres near uni-

versity campuses. The institutes would in many cases offer the best form of organization.

3. The existence of the institutes would ensure that other government agencies really would concentrate on their specific missions in applied research, development, or innovation and that their interest in basic research would be genuine, since they would have to pay for it without performing it themselves. Government departments are often monuments to past problems. Departments of agriculture in many countries are a good illustration of the natural instinct for survival.
4. If mission-oriented agencies build up the basic research capability to solve specific issues, what do they do with their facilities and staff when the answers have been found? This difficulty would hardly arise in the proposed academy because, with proper management, staff could be assigned to new problems more easily and without placing a burden on the people concerned.

It should be stressed that the kind of management the academy and its institutes require would have to be different from the curiosity-oriented basic research organizations in universities. It would have to emphasize personnel mobility and strong links with universities and the users of its results. One result would be a better contact between the basic research scientists in the institute and those needing the information. Another would be higher staff mobility: for instance, having conducted a mission-oriented basic research program for a firm or government agency, a scientist might well decide or be encouraged to transfer and carry the program into the next phase of R&D.

Some people may argue that the kind of management the Committee is suggesting for the proposed academy would not attract good scientists. This fear was not shared by the late Hans Kronberger, who played an important role in the development of Britain's nuclear power reactors. On the basis of his experience, he wrote:

> When the project-oriented R and D laboratories of the Risley organization were set up about twenty years ago, fears were expressed that good scientists would not like the disciplines of defined objectives, fixed time-scales, and financial control; that it would be difficult to attract good people to such an organization and to keep them there. Events have proved that this was not so. On the contrary, the feeling of working for a common aim, the knowledge that success would depend on individual contributions, the fact that the tasks to be carried out by individuals or groups were clearly to be seen on the programme breakdown gave an immense feeling of purpose to all the

> staff. . . . The most effective way of attracting good people to one's organization is to offer work on demanding and challenging projects. The majority of scientists prefer to work on urgent projects in need of solutions, rather than to provide solutions in search of applications.[58]

Reorganization of the government's mission-oriented basic research activities needs the same priorities as those proposed for curiosity-oriented research in universities. The social sciences should receive first priority, in part because of the urgent need to bridge the gaps between theory, methodology, and new research techniques in most of these disciplines but mainly because government agencies have almost completely neglected this sector of mission-oriented basic research—a situation recognized by Arthur Smith when, as chairman of the Economic Council, he stated:

> . . . we may well find that an increasingly mature and knowledgeable appreciation on the part of both government and business of the value of the social sciences will lead not only to greatly enlarged support for such research in the universities and in other research institutions, but also to the development of such research by governments and business organizations themselves.[59]

This institute for mission-oriented basic research in the social sciences that we are proposing here would not conflict with the Institute for Research on Public Policy (IRPP) recommended by Ronald S. Ritchie and recently accepted by the Canadian government. As Mr. Ritchie and the Prime Minister have indicated, the IRPP will concentrate its activities on applied research, development, and social innovation. In a subsequent volume we will suggest some more precise terms of reference for the IRPP, about which it will suffice to say here merely that they are concerned with social systems, such as health, education, social security and urban affairs. Thus the two centres would complement each other, the one proposed by the Committee supplying the basic research in the social sciences requested by the other.

One of the first tasks of the basic research institute would be to work out more sophisticated concepts and methodologies for developing social indicators and social accounting as well as better measures of the quality of life. As Albert D. Biderman has noted:

> Social scientists can contribute to the rational development of sets of standard social indicators in several ways. Among them are the traditional activities of identifying the significance of social phenomena and their interrelationships; devising and refining the conceptual and technical apparatus for the measurement of these phenomena; educating the citizenry for social indicators regarding the meanings, uses, and abuses of social indexes; and lobbying for data series in areas in which they are lacking.[60]

This undertaking will require the integration of skills and concepts developed by economists, political scientists, sociologists, psychologists, historians, and statisticians. Bertram M. Gross believes that "The great advances in the social sciences during recent decades make it possible to establish such a system. The needs of administrators, government leaders and international agencies make it imperative."[61]

Many important scientific challenges would face this proposed new institute. It should get involved with futurology, which is now expanding rapidly in several countries but has not attracted attention in Canada. It should also initiate a special research program on the method of System Dynamics developed by Jay Forrester, Dennis Meadows, and their colleagues at the Massachusetts Institute of Technology and on its application to the Canadian scene. This new technique has been described as:

> . . . a method of computer simulation designed specifically to handle complex social systems. It can deal simultaneously with physical, social, and psychological variables, and it can handle non-linear equations.
>
> The method uses the human perceptions of the relationships that make up a complex system. Each of these relationships can be discussed by experts without the necessity for specialized mathematical language, and when they agree on what the relationship is, it can be represented mathematically in the instructions fed to the computer.
>
> Once the information has gone into the computer, the computer can carry out a simulation—seeing, for example, how a 2% yearly gain in population will affect the total system over a period of years.
>
> System Dynamics uses the human mind to do what humans can do best—recognize and analyze the separate elements in a social system—and the computer to do what a computer can do, but humans cannot—calculate the simultaneous operation of all these elements over a period of time.[62]

The life sciences should have second priority, with special emphasis on human health sciences. A number of government agencies are already involved in this area. Integrating and centralizing all this work in one institute would create a stronger nucleus, which could then be extended into the gaps, especially in molecular biology.

The basic research done by the Canadian government in the physical sciences has been concentrated mainly in NRC, but other agencies—the Defence Research Board, the Department of Energy, Mines and Resources, and AECL among them—are also involved. It should be integrated in the foundations whenever possible. For instance, as AECL has moved to development work and innovation, the mission-oriented basic research it has been doing since the beginning now appears to be much less directly related to its

mission. When the government's basic research in the physical sciences is integrated, normal expansion in this area should be provided for.

Some may argue that integration of the government's basic research in the proposed academy would unduly isolate this activity and turn the three institutes into ivory towers. This danger will be minimized by staff exchanges, by the contractual arrangements they will have with universities, industry, and government agencies, and by the kind of management they have. Moreover, the Committee believes that this small risk will be outweighed by the advantages of having all the basic scientists together under the same administrative roof, which will provide them with working conditions better suited to their skills and motivation and with the opportunity to work together as multi-disciplinary teams. The proposed integration would also minimize duplication in an area where excellence is a scarce resource.

Before bringing these activities together the Minister of State for Science and Technology should review the basic research programs of all government mission-oriented agencies to see if they are justified and, if they are, whether some of them, and even some of the research units, could be usefully attached to universities. This should become a continuing process, so that some of the projects and units of the proposed academy could later also be assigned to universities, thus enabling the institutes to rejuvenate themselves and redefine their orientation from time to time.

The Committee therefore recommends:

1. That the Minister of State for Science and Technology undertake a detailed review of the basic research activities carried out by all government agencies to see if they are justified and, if so, to consider whether some of them could not be advantageously transferred to universities;

2. That in the future most basic research activities of the Canadian government be concentrated in a national research academy, with three institutes for the physical sciences, the life sciences, and the social sciences, with the purpose of filling gaps in basic research, especially in the social sciences and the life sciences; and

3. That a substantial portion of the work of the institutes be performed at the request of government agencies and private firms on a fee basis.

CONCLUSION

The Committee's recommendation of a specific maximum target of expenditures for basic research to be achieved by 1980 would substantially reduce

the share of the national R&D effort devoted to this activity but the size of the budget spent for that purpose would rise substantially up to 1980, provided that worthwhile projects and programs are submitted for public support.

In proposing a new strategy for the support of basic research and the development of a better national capability, we have emphasized quality rather than quantity. Our proposal is founded on the criteria of scientific excellence and social merit. It would put our country in a stronger position to extend the pool of basic knowledge and thus meet its international obligation more efficiently while taking proper account of Canadian requirements.

Our strong emphasis on excellence could alter the climate surrounding curiosity-oriented basic research in Canada. It would make it more difficult for pure scientists in universities and other similar institutions to qualify for support but quality would be more generously rewarded. The number of research grants would probably decline but their size could be substantially increased wherever real excellence is found. Thus the proposed strategy should produce a greater number of top basic scientists in Canada and help to keep them here, to repatriate some of those who have emigrated, and to induce more foreign internationally recognized scholars to come and continue their careers in our country.

The main function of the proposed national research academy would be to carry out oriented basic research for industry and government mission-oriented agencies when it could not be properly provided by universities, and in general to complement the curiosity-oriented basic research performed in the academic sector. The institutes could improve the quality of research by greater concentration and could facilitate team work and the multidisciplinary programs that are essential in mission-oriented basic research.

Under our proposed overall strategy the scientists most skilled and best motivated for scientific discovery would receive increased public support to do pure research. Given the need for increased effort in applied fields of investigation, teaching, and other worthwhile missions, the Committee hopes that many trained scientists will opt for this work, where they would undoubtedly be happier as individuals, more useful to society, and consequently more entitled to public support than if they were employed in a less successful career of basic research.

NOTES AND REFERENCES

1. Eric Ashby, "Science and antiscience", *Nature,* April 2, 1971, p. 284.
2. Ibid.
3. Harvey Brooks, *The Government of Science, op. cit.,* pp. 112 and 114.
4. Abraham H. Maslow, *The Psychology of Science, A Reconnaissance,* Henry Regnery, Gateway Edition, Chicago, 1969, pp. 22-23.
5. Ibid., p. 30.
6. Ibid., p. 33.
7. Thomas S. Kuhn, "Normal Science as Puzzle-solving", Chapter IV of *The Structure of Scientific Revolutions,* International Encyclopedia of Unified Science, Vol. 2, No. 2, University of Chicago Press, Second Edition, Enlarged, 1970, pp. 35-42.
8. *A Framework for Government Research and Development,* H.M.S.O., London, November 1971, p. 3.
9. Kuhn, *op cit.*
10. Ibid., p. 10.
11. Quoted by Kuhn, ibid., p. 151.
12. Paul A. Samuelson, "The *General Theory* (3)", Chapter XIII of *The New Economics: Keynes' Influence on Theory and Public Policy,* edited by Seymour E. Harris, Alfred A. Knopf, New York, 1947, p. 146.
13. Kuhn, *op. cit.,* p. 26.
14. Ibid.
15. Ibid., p. 27.
16. Jacques Barzun, *Science: The Glorious Entertainment,* Harper and Row, New York, 1964, pp. 120 and 122.
17. Ibid., pp. 128, 129 and 131.
18. Jerome B. Wiesner, "Science, Technology, and the Quality of Life," *Technology Review,* December 1971, p. 15.
19. Richard B. Freeman, *The Market for College-Trained Manpower: A Study in the Economics of Career Choice,* Harvard University Press, Cambridge, 1971, p. 229.
20. John Ziman, *Public Knowledge: An Essay Concerning The Social Dimension of Science,* Cambridge University Press, 1968, pp. 128 and 130.
21. *Science in Canada,* edited by J. D. Babbitt, University of Toronto Press, 1965, pp. 54 and 56.
22. Senate Special Committee on Science Policy, *Proceedings,* No. 41, April 24, 1969, pp. 5194-5195.
23. *A Science Policy for Canada,* Volume 1, Table 3, p. 125.
24. "Nations can publish or perish", *Science and Technology,* October 1967, pp. 84-90.
25. Karl W. Deutsch, John Platt, Dieter Senghaas, "Conditions Favoring Major Advances in Social Science", *Science,* 5 February 1971, pp. 450-459.
26. David D. Rutstein, *The Coming Revolution in Medicine,* The M.I.T. Press, Cambridge, 1967, p. 147.
27. Quoted in Science Council of Canada, Report No. 4, *Towards a National Science Policy for Canada,* p. 25.
28. "Social responsibility (I): The impact of social responsibility on science", *Impact of Science on Society,* Vol. XXI, No. 2, April-June 1971, p. 122.
29. J. Bronowski, "The Disestablishment of Science", *Encounter,* July 1971, p. 15.
30. Anthony Wedgwood Benn, "Towards a New Dictatorship?", *Encounter,* September 1971, p. 93.
31. *The Social Responsibility of the Scientist,* edited by Martin Brown, The Free Press, New York, 1971.
32. Hilary and Steven Rose, *Science and Society,* Allen Lane, London, 1971, p. 269.
33. Bronowski, *op. cit.,* p. 15.
34. Alvin M. Weinberg, "Criteria for Scientific Choice" and "Criteria for Scientific Choice II", from *Criteria for Scientific Development,* edited by Edward Shils, *op. cit.,* pp. 81 and 25.

35. Dr. H. L. Welch, chairman of the University of Toronto's department of physics, says that Herzberg has collected around him a very fine staff and that he is the "mastermind" behind this development (CBC, "This Country in the Morning", November 3, 1971). The official announcement of the Swedish Academy of Science said: "Under Herzberg's dynamic leadership his laboratory attained a unique position as the foremost center for molecular spectroscopy in the world." (Official English translation supplied by Swedish Embassy, Ottawa.)
36. Ziman, *op. cit.*, p. 145.
37. Graham Jones, *The Role of Science and Technology in Developing Countries,* published for The International Council of Scientific Unions by Oxford University Press, London, 1971, p. 126. The relation between age and a scientist's productivity and the problem of the "age structure" of laboratory staff have also been reviewed by a Czech writer, Jan Vlachy in "Remarks on the Productive Age", *Teorie A. Metoda,* II/3, Prague, 1970, pp. 121-150.
38. G. M. Dobrov, "Science Policy in the Soviet Union", from *Decision-Making in National Science Policy,* edited by De Reuck, Goldsmith and Knight, A Ciba Foundation and Science of Science Foundation Symposium, J. & A. Churchill Ltd., London, 1968, p. 194.
39. Ibid., p. 195.
40. *OECD, Review of National Science Policy; Canada,* Paris 1969, p. 290.
41. Senate Special Committee on Science Policy, *Proceedings of Phase I,* Queen's Printer, Ottawa, 1968, pp. 188-189.
42. *Science and Society, op. cit.*, p. 269.
43. "Disestablishing Science ", *Encounter,* September 1971, p. 91.
44. "Criteria for Scientific Choice", *op. cit.,* p. 23.
45. OECD, *op. cit.,* p. 295.
46. Frank Kelly, *Prospects for Scientists and Engineers in Canada,* Special Study No. 20, Science Council of Canada, January 1971.
47. Ibid., p. 6.
48. "Conditions Favoring Major Advances in Social Science", *op. cit.*
49. Senate Special Committee on Science Policy, *Proceedings,* No. 30, Feb. 13, 1969, pp. 4118.
50. Surveys by M. Timlin and A. Foucher, by Bernard Ostry; Robin F. Badgley, "Sociology in Canada: Past and Future"; Harry G. Johnson, "Canadian Contributions to the Discipline of Economics since 1945", *Canadian Journal of Economics,* February 1968.
51. Arthur J. R. Smith, "The Social Sciences and the 'Economics of Research' ", address to the Royal Society of Canada, Calgary, Alberta, June 3, 1968, pp. 5-6.
52. The Council noted, for instance, that the percentage of Canadians on faculty in these sectors in Ontario was then only 47.4 per cent for the humanities and 53.6 per cent in the social sciences, (*13th Annual Report,* 1969-1970, p. 15).
53. *The Role of the Federal Government in Support of Research in Canadian Universities,* Science Council of Canada, Special Study No. 7, Queen's Printer, Ottawa 1969, pp. 209-210.
54. Proceedings on the Question of Growth, Employment and Price Stability, Standing Senate Committee on National Finance, No. 12, p. 37.
55. Presidential address to the American Economic Association, "Theoretical Assumptions and Non-observed Facts", *American Economic Review,* March 1971, p. 4.
56. Ibid.
57. Jack A. Morton, "From Research to Technology", in *The R&D Game,* The M.I.T. Press, Cambridge, 1969, pp. 213-235.
58. Hans Kronberger, "How the Atom Paid Off", *The New Scientists,* edited by David Fishlock, Oxford University Press, 1971, pp. 23-24.
59. Arthur J. R. Smith, "The Social Sciences and the 'Economics of Research' ", *op. cit.,* p. 6.
60. Albert D. Biderman, "Social Indicators and Goals", in *Social Indicators,* edited by Raymond A. Bauer, The M.I.T. Press, Cambridge, 1966, p. 145.
61. Bertram M. Gross, "The State of the Nation: Social Systems Accounting", in Bauer, *op. cit.*, p. 155.
62. *The Futurist,* August 1971, p. 149.

APPENDIX 1

LIST OF RESEARCH GRANTS AWARDED BY THE CANADA COUNCIL FOR THE SOCIAL SCIENCES AND THE HUMANITIES IN 1969-70*

For research on a bilingual glossary of terms in use in Quebec law, designed to assist in computer retrieval of legal information	$30,000
For research on the semantics and metaphysics of science	26,800
To continue research on the impact of innovation and technical change on society	14,000
To complete a series of studies demonstrating the usefulness of modern social science techniques for research in the humanities	17,991
To continue research on genetic aspects of the French Canadian population	30,000
For work on a volume, *France in America*, preparatory to undertaking a major research program on the social history of Canada	10,500
For research on an econometric model of the links between the economies of Canada and the United States	22,700
To continue research on the human considerations involved in architecture and environmental design	12,000
For further development and testing of a computer system to assist group problem-solving	22,098
For a world-wide survey aimed at determining which of the languages spoken by at least 10,000 people have been standardized in written form	15,000
For research on law-making powers under federal constitutions and in international law	13,600
For research on social and institutional change in China	20,840
To continue research on the role of parties and elections in the Canadian political system	6,213
To continue interdisciplinary research on the impact of modernity on traditional modes of life in the Eastern Arctic	85,000
For interdisciplinary research on a computer system adapted to the needs of the social sciences	25,000
For research on the relationships between business fluctuations in Canada and the United States	20,872
To continue research on the process of political change in contemporary Czechoslovakia	7,700
To continue research on the biological basis of human behaviour	21,300
For research on the importance to human health of mineral trace elements in foods	35,000
To continue research on Canadian economic interdependence and policy autonomy	75,000
For research on determining the authenticity of texts attributed to Plato and Aristotle through stylistic analysis with the computer	14,000
To continue research on unintended bias in social science research	8,530
For research on how participation in adult education relates to involvement in civic affairs	13,591
For archaeological excavation of a Greco-Roman-Byzantine site at Anamur in southern Turkey	14,700
For interdisciplinary research on the response of Indian populations in British Columbia to changes in their environment	9,047

*The Canada Council, 13th Annual Report 1969-70. Ottawa, 1970.

For research to make a system of measurement of authoritarian attitudes (the "Balanced F Scale") a more accurate tool of psychological research	10,250
To continue research on the changing concept of caste in India	8,277
For research on international trade and early economic development in various societies	6,981
To continue research on the connection between individual personality and political attitudes	38,010
To continue anthropological research on three Indian cultures in Puebla State, Mexico	26,845
For research on the labour movement in Quebec	10,000
To continue research on patterns of illness within families	32,881
For research on the effect of an isolated environment on a population of European origin in the Caribbean	9,850
For research on the psychology of art and esthetic motivation	24,602
To continue research on criminality in women	22,000
To continue research on a bibliography of Neo-Latin literature in seventeenth century France	19,554
To continue research on the psychology of human relationships	7,500
For research on the sociology of elections in Montreal	16,835
To continue research on prehistoric culture at the neolithic site of Erbaba, in Southwest Turkey	9,400
To continue archaeological excavation of prehistoric sites along the Fraser River near Yale, British Columbia	25,110
For research on the foreign policy of Israel	19,454
For archaeological research in Central Colombia in the ancient Quimbaya cultures	12,409
To continue anthropological research comparing two Eskimo populations, at Kotzebue, Alaska, and Eskimo Point, N.W.T.	17,550
For geographical research on areas of relative economic growth and decline in the United States	5,686
For research on a critical compilation of source material on the history of New France from 1616-1680	13,300
To continue research on changes in the status of women in Quebec	17,814
For interdisciplinary research on the effect of computerized information retrieval systems on the freedom of the individual	10,380
For research on the rules of international law applied to the private sector in Canada (conflict of law rules)	7,000
For research on the economic and geographic aspects of the St. Lawrence Seaway during its first nine years, 1959-68	6,250
For research on the agricultural geography of India	5,910
For research on creative innovation in regional landscape planning	5,431
For research on the bureaucratic elite in the developing countries of West Africa	21,208
For research on basic principles for the use of technical innovations in urban architecture and design	9,962
For research on the political psychology of individuals in English Canada, French Canada and the United States	15,028
To continue research on a quantitative model to forecast developments in the Canadian economy and to simulate the effect to economic policies or events	8,993
For research on themes taken from the Apocalypse in the work of Russian "Symbolist" writers	5,275
For computer analysis of English prose style in the Renaissance and Restoration (1575-1700)	5,400
For research on a critical edition of the 13th century epic poem, *Auberi le Bourguignon*	6,661
For research on a chronology of all works in literature, history, philosophy, politics and the sciences published in France during the Enlightenment, 1680-1789	14,738
For research on the nature and effectiveness of monetary policy in Canada and in other countries	12,800

For research on current developments in industrial relations in Western Europe	5,885
For research on a budgeting system for programs involving the federal, provincial and municipal levels of Canadian government	6,720
For research on the psychology of human emotions	17,000
To continue research on quantitative models used in economic analysis	32,048
To continue research on a complete catalogue of the works of the 17th century Italian artist, Mattia Preti	6,255
To continue research on a bibliography of the English writer Hilaire Belloc	8,000
For archaeological research on the vase-painting of ancient Cyprus	5,595
For research on the "brain drain" from underveloped to technologically advanced countries	36,150
For psychological research on trust in individuals who are outside the social norms of a group	9,750
For research on the 16th century background of modern science	9,022
For research on the sense of ethnic identity and the social organization of minority groups in Winnipeg	15,450
For research on the psychology of creative artists	8,181
For research on a system designed to test rules generated by a "transformational" grammar of French, and which will also be available for research on other languages	16,440
For research on the development of the trade union movement in Jamaica	9,487
For research on Canadian contract law	6,000
For research on an economic analysis of crime and criminal justice in Canada	12,837
For research on the psychology of conformity in social behaviour	13,918
To continue research on contemporary German politics	17,624
For research on the sociology of the family	9,288
For research on frontier settlement in Asia	11,892
For research on a sociological theory of developing societies	7,000
For research on a critical evaluation of the work of the Victorian novelist, George Gissing	5,625
To continue research on the institution of the Ombudsman in Alberta	18,437
For psychological research on the effect of foreknowledge on human reaction to unpleasant events	14,345
For research on the role of the nobility in the social and political history of Japan	8,750
For research in linguistics on the mental skills involved in oral translation	6,120
For research on an etymological and historical dictionary of Old French	30,000
To continue preparation of a dictionary of linguistic terminology	17,673
For research on the impact of Italian literature on Latin American writers of the late 19th and early 20th centuries	5,616
To continue research comparing isolated rural communities in Quebec, Prince Edward Island, New Brunswick and Alberta	38,605
For archaeological excavations at the site of the early Christian monastery of Alahan in Southern Turkey	15,000
For research on the history of the public administration of Quebec since 1867	17,400
For research on a biography of the former Prime Minister of Canada, Mackenzie King, during the war years, 1939-45	5,974
For research on political change in British Honduras	6,755
To continue psychological research on the relationships between the moral behaviour of children and child-rearing practices followed by mothers of several ethnic groups	8,494
To continue research on the psychology of individual behaviour in the face of unavoidable events	9,502
To continue research on how various social characteristics of a community affect juvenile delinquency	5,665
To continue research on the reconstruction of the debates in the Legislative Assembly of Quebec, 1867-1900	17,020
For research on French Canadian literature in the first half of the 19th century	5,566

To continue research on the letters and journals of Fanny Burney (Mme d'Arblay), an 18th century British novelist and journalist	15,125
To continue research on Negro communities in Nova Scotia	7,600
To continue research on developing psychological personality tests in a Canadian context	6,000
For interdisciplinary research on the prehistory of Ontario	46,850
For research on the role of the kingship in modern Iran	9,370
To continue research on the changing role of small agricultural holdings in the British Caribbean and its relations to economic and political development since 1800	42,484
For research on African psychological studies and their implications for traditional psychological theory	8,000
For interdisciplinary research on early man in the New World, and the origins of Indian peoples in northwestern Canada and Alaska	24,740
For research on the validity of intelligence tests	5,660
For research on early Italian keyboard music (Antonio Valente's *Intravolatura de Cimbalo,* Naples, 1576)	5,375
For research on measuring and evaluating the impact of man's development activities on the landscape	11,609
To continue research on the grammars of two American Indian languages, Ojibwa and Odawa	12,797
For research on the role of the Canadian public service in the formation of government policy	8,225
To direct preparation of Volumes IV and V of the comprehensive survey, *Contemporary Philosophy/La Philosophie contemporaine*	14,330
For a statistical survey of the population of all the countries of the world by mother tongue	17,504
For research on the psychology of authoritarianism	11,575
To continue research in Vancouver and Winnipeg on how individuals are influenced to take an active role in politics	43,000
For archaeological excavation of the old French settlement of Roma at Brudenell Point, P.E.I.	13,116
To continue sociological research on landlord-tenant relations in Greater Montreal	14,605
To continue research on the social and psychological aspects of second-language learning and bilingualism	17,050
For research on the historical significance of the Royal Ontario Museum's extensive collection of ancient Chinese bronze weapons	19,700
To continue research on the relations of social class and politics in Vancouver	7,000
To continue research on the sociology of organizational change	8,510
For research on federal and provincial political parties in the Quebec City region	8,800
To continue experimental research on phonetics in French	23,220
For research on the role of scientific instruments in the history of 18th century science	5,456
For research on the scope and significance of the changing attitudes of policy-makers of the U.S.S.R. towards the Cuban Revolution	8,192
For research on a theoretical model of the science of architecture	11,590
For research on conflicting interests in the multi-national business firm	27,638
For historical research on British objectives in World War I	12,890
For exploratory research on changes in mentality and behaviour brought about by modernization in a developing African society	12,258
For psychological research on the influence of environment and heredity on children (conformity and autonomy)	9,205
To continue comparative research on the psychological effects of the change from a traditional to a modern society among Eskimos and Central Africans	17,642
To continue research on the history of mathematics since 1800	8,650
To prepare a critical edition of the complete works of the Mexican political pamphleteer, Pablo de Villavicencio (1792-1832)	10,501

For research on immigration in the Manitoba-Minnesota region from 1860-1920	6,939
For research on a bibliography and critical editions of papers and documents on the Loyalists of the American Revolution	19,600
For research on the theory of international trade	9,396
For sociological research on the adaptation of immigrant families from an under-developed country to a modern industrial society	8,124
To continue research on the sociology of urban housing	39,000
For archaeological excavation of prehistoric sites near Swift Current, Saskatchewan, and survey of other possible sites	14,090
For research on homesteading in Saskatchewan from 1912 to 1923	6,398
To continue sociological research on contemporary attitudes towards religion	13,852
For research on the learning capacities of children of different social backgrounds	7,400
To continue research on reconstruction of the debates of the Legislative Assembly of the United Canadas in the pre-Confederation years 1841-1867	7,000
For preparing a permanent archival record of Indian languages of the northwest coast of Canada, many of which will be extinct in a few years	5,400
To continue research on the economic and social development of Lower Canada, 1791-1812	8,000
For research on the theory of concepts of the 18th century Anglo-Irish philosopher, George Berkeley	5,375
For research on the Canadian Divorce Act of 1968	6,000
To continue archaeological excavation of ancient Maya remains at Altun Ha, British Honduras	21,254
For research on a bilingual glossary of Canadian legal terms used in both Common Law and the Civil Code	36,000
For research on migrations from India in the 19th and 20th centuries	9,300
For interdisciplinary research, combining mathematics, statistics and computer programming, on techniques of prediction and classification in criminology and other social sciences	13,050
For geographical research on company towns in remote areas	5,248
For the design and pre-test of techniques and the assessment of feasibility of a large-scale research project on the decisions of Ontario youth about education beyond high school	17,888
To continue research on a comparative study of special interest groups in the political system of Canada and the United States	44,515
To continue research on the development of a "transformational" grammar of French	28,000
To continue geographical research on the growth of Greater Montreal on the south shore of the St. Lawrence	18,090
To continue historical research on attitudes in the Maritimes towards the United States from 1784-1896	11,645
For archaeological research on reliefs and inscriptions at the temple of Osiris-Ruler-of-Eternity at Karnak, Egypt	7,940
For psychological research on human behaviour (reinforcing properties of attitudes)	6,700
For geographical research on road-traffic intensity and the growth of cities in Quebec	16,500
For research on an Atlas of Saskatchewan	7,085
To continue research on the housing and social integration of immigrants and ethnic groups in Toronto	118,000
For anthropological research on the symbolism of the American Indian Sun Dance	6,500
For linguistic research on the Scots Gaelic dialect of Cape Breton Island, Nova Scotia	6,562
For research on a scientific and historical grammar and a dictionary of Papiamento, a creole language of the Caribbean	6,800
For research on the poet-artist William Blake's water colour illustrations of Edward Young's long 18th century poem, *Night Thoughts*	7,250
For psychological research on what makes bystanders intervene or stand aside in an emergency	10,550
For research on the psychology of knowing	10,000

To continue research on the psychological processes underlying hostility and aggression	8,650
To continue research on the ethnography of the Eskimos of New Quebec	41,390
For research in industrial psychology on factors influencing task performance and satisfaction	8,175
To continue research on the preparation of an edition of the Royal Ontario Museum's collection of ancient papyrus texts and inscribed fragments of pottery	8,200
For anthropological research on teaching methods in different kinds of societies in Canada and Africa	42,101
For anthropological research on the mythology of the Indian peoples of Quebec	21,375
To continue research on the determinants and effects of power in a variety of Canadian business organizations	26,108
To continue archaeological exploration of three prehistoric sites in the Bekaa Valley of Lebanon	14,343
For research on improved methods for testing the intellectual potential of individuals who live under economically deprived conditions or come from different ethnic backgrounds from the majority	5,550
For research on the theory of economic geography (dynamic locational systems)	6,954
For linguistic research on Newfoundland family and place names	8,092
For archaeological excavation of the ancient Roman theatre in Vienne, France	5,900
For research in social psychology on the role of verbal communication in building up relationships between individuals	11,850
For research on the characteristics of effective university teaching	12,000
For a critical study and translation of the *Anticlaudianus*, by the 12th century scholar Alain de Lille	6,190
To continue research on industrial conflict in France from 1830 to 1960	24,800
To continue archaeological excavation of an Iron Age site at Gravina, Southeast Italy and to undertake a topographical survey of the Bradano Valley for other ancient remains	10,550
For research on the Saskatchewan Liberal Party from 1905 to 1970	5,156
For archaeological excavations at a Greco-Roman-Byzantine site near Anamur in Turkey	14,650
For archaeological excavation of the prehistoric site at Ganj Dareh, Iran	15,355
For research on the political career of the Rt. Hon. John G. Diefenbaker	15,992
For research on the role of skepticism in ethics and moral philosophy	6,660
For research on a dictionary of Newfoundland English	7,375
To continue work on a collection of oral and printed documentation on Canadian political developments as revealed through the career of the Honourable Paul Martin	14,642
For research on the theory of criminology (social reaction to various kinds of deviant acts)	24,700
For research on the responses of intellectuals to technology in the modern world	8,560
To continue research on a history of the Mennonites in the U.S.S.R.	5,990
For archaeological analysis of a large find of late Bronze Age pottery at Shechem, Israel	6,158
To continue research on the ethnography of the North Shore region of Quebec	72,910
For archaeological excavation and study of prehistoric Eskimo sites at Sagley Bay, Labrador	10,750
For research on the make-up and interpretation of the statistics used to measure economic growth in Canada	9,000
For research on social thought and nationalism in French Canada from 1960 to 1966	9,945
To continue research on the conditions under which French-Canadians outside Quebec retain or lose social and cultural distinctiveness	36,722
For anthropological research on the art and architecture of Northwest Coast Indians	5,801
To continue research on the psychology of group decision-making	9,225
For research on the history of 17th century Italian art	10,990

To continue research on the political attitudes of various agricultural groups in the United States	10,079
For research on the use of the computer in analyzing early Bronze Age pottery and other archaeological finds	9,500
For research on the attitudes of English-speaking and French-speaking students in Quebec about school and education	14,920
For research on econometric models of savings and financial flows in Canada from 1962 to 1967	27,640
For research on the moral philosophy of the 13th century thinker, Thomas Aquinas (relationship of intellect and will in the human act)	5,575
For geographical research in Scotland on the problems of northern settlement in areas that have been occupied for a relatively long time	7,496
For research on the geographical theory of planning for regional development	9,090
For research on a critical edition of the *Histoire du Canada* of the 19th century historian, François-Xavier Garneau	22,620
For research on the community system in the Prairie provinces and its role in national development	13,550

15

INDUSTRIAL INNOVATION: TARGETS AND THE PRIVATE ENVIRONMENT

In Chapter 11 we described the tremendous potentialities of science and technology for improving our well-being and enhancing the quality of life in Canada. We also pointed out that most advanced industrialized countries, Canada among them, had slipped into an economic growth spiral in the course of attaining affluence and were in some danger of imposing a too heavy burden on the natural environment. The course of our future is thus a dilemma. Obviously we will have to put a larger portion of our effort into overcoming social and environmental problems than we have in the past. Equally obviously the ability to continue that effort will depend on maintaining the strength of the economy.

In some respects the situation resembles a scenario first presented in 1833 by a mathematical amateur named William Forster Lloyd, in a little known pamphlet called *Two Lectures on the Checks to Population.* An Admirer of this fable, Garrett Hardin, has summarized it:

> The tragedy of the commons develops in this way. Picture a pasture open to all. . . . As a rational being each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, "What is the utility *to me* of adding one more animal to my herd?" This utility has one negative and one positive component.
>
> > 1) The positive component is a function of the increment of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly +1.
> >
> > 2) The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility for any particular decision-making herdsman is only a fraction of −1.

> Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another and another. . . . But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is *locked into* a system that compels him to increase his herd without limit—in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. *Freedom in a commons brings ruin to all.*[1] [Emphasis added]

It is possible to regard advanced countries as being "locked into a system" that compels them to maintain economic growth "without limit—in a world that is limited". The risk of bringing "ruin to all" is the haunting prospect presently hanging over the advanced industrialized countries.

But of course Lloyd's fable is still just that, a fable. To insist on an immediate halt in economic growth, even if it were possible, would be to live by fashionable extremes rather than rationalities. We may in time move closer to Zero Economic Growth, as may the rest of the developed world. Meanwhile we need to promote at least an equal economic growth, even if we also have to expend rather more effort than before on minimizing its negative impact on the environment and the quality of life in our larger urban communities.

Considering, then, how we might expand our economy in the 1970s, we have to recognize that it is based on a rich resource endowment, a relatively sophisticated manufacturing industry and a fast-growing tertiary or service sector, which now employs over 60 per cent of the labour force.

The spectacular expansion of service industry as a contributor to employment and Gross National Product has led some people to believe that services will independently expand the economy for an indefinite period. It is now commonly said, for instance, that the economy has become post-industrial. It is quite true that the government sector can play a dynamic role for some time, but most other services mainly respond to the growth of the primary and secondary sectors of the economy. The country cannot expect to base its long-term growth strategy on services as prime movers, although their continuing expansion can be expected if other dynamic factors are at work to sustain it.

The direct contribution that the primary industries, such as mining, make to overall growth and employment is significantly lower than the contribution of secondary manufacturing per dollar of investment, one reason being that the primary industries are usually more capital-intensive. The indirect impact —that is, the effect on capital formation, and therefore on the net value of production and employment—of resource-oriented industries on other sectors, mainly services and public utilities, is also lower than that of manufacturing.

Richard E. Caves and Grant L. Reuber have studied the secondary impact of foreign investment and concluded that ". . . a dollar of direct investment was typically associated with more than a dollar of Canadian capital formation, generally between $1.50 and $3.00". They also observed, among other things, that complementary investment tends to be high—that is, about $3.00—"when foreign investment is directed towards Canadian secondary manufacturing, but low [that is, nearer to $1.50] when it is directed to petroleum and mining".[2]

There is no apparent reason why this effect should not also apply in domestic net direct investment. We conclude that, all things being equal, the complementary investment generated in business service industries and public utility enterprises by an extra dollar invested in secondary manufacturing is about $3.00, or twice as much as is generated by extractive industries.

All this explains why in this chapter and the two following, while dealing with industrial innovation, we put the emphasis first on the manufacturing sector and secondly on resource-oriented industries. It does not mean that there is no need to innovate in the service sector, and in fact we will have a good deal to say about the innovative process in Canadian social systems in a subsequent volume.

We have decided to concentrate on technological innovations as a source of economic growth and employment. Although we use the word *technology* in its broadest sense, defined by Emmanuel G. Mesthene as "the organization of knowledge for the achievement of practical purposes", we recognize that non-technological innovations can also be most useful. Indeed, as we consider the private and government climate for economic growth, we suggest a number of non-technological innovations that are urgently needed in Canada.

Since 1969, the external and internal climate for secondary manufacturing industries has deteriorated seriously. The loss of Commonwealth preferences and Britain's impending entry into the European Common Market will have a negative impact on Canadian sales abroad. Similarly, the recent emergence of protectionism in the United States, reflected in the import surcharges and the impending establishment of tax-free U.S. Domestic International Sales Corporations (DISC), could seriously restrict the export of Canadian manufactures to the important U.S. market.

We hope these restrictions will be only temporary. We cannot believe that the world, and the Americans in particular, have forgotten the lesson of the 1930s when the rise of protectionism and the ensuing international trade wars damaged economic conditions all around the world. There are more positive remedies to the American dollar crisis than the imposition of trade barriers. On the other hand, there is no doubt that world trade is entering a

new era and that the 1970s will witness a realignment of traditional trade channels among nations that may well be less favourable to Canadian interests.

Signs of domestic weaknesses are also appearing. The gradual erosion of tariff protection, which has been accepted by Canadian governments as one of the costs of obtaining easier access to world markets for our primary products and our resource-based industries, has contributed to the gradual weakening of secondary manufacturing industry. So have rising costs, industrial fragmentation, and reliance on imported technology. The exploitation of our most economical hydraulic sites, which was a strategic factor in industrial location, is over. Some of the pulp and paper industry is experiencing structural difficulties while facing stiffer competition on world markets, and this industry is not alone in experiencing difficulties, as the Committee has heard *(see Chapter 9, Volume 1)*. This evidence indicates that the Canadian economy will face new difficulties in the 1970s if we do not succeed soon in developing a new industrial policy based on a more active and coherent technology strategy.

Since the beginning of the second major technological revolution in the early 1900s, Canada and its governments have adopted a passive strategy based on imported technology and responding mainly to the growing external demand for our abundant natural resources and primary products. It is becoming increasingly clear that this policy of depleting our resource base for minimal economic returns will become more and more untenable in the future. Exports of raw materials have no great multiplier effect, particularly in terms of employment opportunities.

World supply and demand in this sector in the 1970s will still be more or less in equilibrium whether or not the Canadian contribution is expanded. Most other major suppliers of industrial raw materials and other primary products have no alternative, at least in the near future, but to continue to export these products in increasing quantities in order to grow, because they lack a sufficiently broad, developed industrial and technological base. In Canada, however, we have such a base, which can be further extended and strengthened with the proper strategy.

But many experts now agree that the world in the 1980s will be moving rapidly toward a permanent state of scarcities of both renewable and non-renewable resources.[3] We showed in Chapter 11 that since the early 1800s mankind has lived in a period aptly described as the "exponential era", which will almost inevitably lead to the realization that nature's resources are finite. The System Dynamics Group at MIT has accumulated an impressive body of evidence that indicates an approaching point of exhaustion.[4] The group has

calculated (*column 3, table 17*) how long the present known reserves of a number of important mineral resources will last given the projected rate of growth in their use during the period 1970-2000. These figures are compared with the figures normally used to measure future resource availability, which assume no change in the current rate of usage (column 1).

Table 17—Projected Depletion of World Mineral Resources

Resource	Static Index	Projected Usage Rate of Growth 1970-2000	Exponential Index
Aluminum (bauxite)	100 Years	6.4 %/Year	34 Years
Chromium	420	2.6	95
Coal	2300	4.1	111
Cobalt	110	1.5	60
Copper	36	4.6	21
Gold	11	4.1	9
Iron	240	1.8	93
Lead	26	2.0	21
Manganese	97	2.9	46
Mercury	13	2.6	13
Molybdenum	79	4.5	34
Natural gas	38	4.7	22
Nickel	151	3.4	53
Petroleum	31	3.9	20
Platinum	130	3.8	47
Silver	16	2.7	13
Tin	17	1.1	15
Tungsten	40	2.5	28
Zinc	23	2.9	18

SOURCE: These estimates were compiled by the M.I.T. System Dynamics Group from U.S. Department of the Interior, *Mineral Facts and Problems*, U.S. Government Printing Office, Washington, D.C., 1970.

When the usage rate of growth is taken into account, we see that traditional forecasts can create a false sense of security and that continuing exponential rates of growth have serious implications. This pessimistic outlook was confirmed recently by the Petroleum Press Service:

> Though there is not likely to be any actual shortage of oil even beyond the 70s, the era of lavish potential surplus continually threatening the price structure—the buyers' market of the 60s—is over. In a long-term sellers' market, the host governments may make fresh demands.[5]

Recently the problem of ore depletion was brought to the fore in the U.S. by Hollis M. Dole, Assistant Secretary of the Interior, who noted that " . . . easily accessible high-grade ore deposits either have been or are being rapidly

exhausted . . .".[6] He said an acute shortage of raw materials would occur in future decades. One contributing factor, he claimed, was a lack of technology for the profitable extraction of low grade ores. John McHale is also concerned about this problem and has recently documented possible shortages of mineral resources in some detail.[7]

The rapidly accumulating evidence of growing scarcities, coupled with the economic and demographic spirals noted earlier, has led M. King Hubbert to conclude:

> It now appears that the period of rapid population and industrial growth that has prevailed during the last few centuries, instead of being the normal order of things and capable of continuance into the indefinite future, is actually one of the most abnormal phases of human history. It represents only a brief transitional episode between two very much longer periods, each characterized by rates of change so slow as to be regarded essentially as a period of non-growth.[8]

In this context, the conventional Canadian economic strategy of encouraging the rapid exploitation of our natural resources and rising exports of raw materials appears to be most unwise. If we were to conserve these resources regardless of how other countries deplete theirs, we would reap much greater benefits in the future. It has been suggested that this might not be ultimately beneficial because new technology will in time be developed for the economic exploitation of the poor quality resources that will be left in most countries. Even then, however, the cost of exploiting poor quality ores is sure to exceed the cost of exploiting rich deposits. And it is not certain that the hypothetical technology ever will be developed.

If these reports about the rapid rate of depletion of world
~~If, then, we have the rational decision, as we should, to reduce the rate of~~
to be correct, then Canada should develop a flexible strategy for the future use of its own resources, in the light of its own reserves compared with future world supplies and requirements. This flexible approach might mean, for instance, that we should export as much coal as we can, but review more carefully the rate of exploitation of lead, zinc, and natural gas. Such a selective approach would undoubtedly produce a lower rate of growth in the exploitation of many of our natural resources.

If, then, we take the rational decision, as we should, to reduce the rate of growth in the exploitation of resources until we are in a stronger bargaining position on world markets, and if we want to continue to improve our standard of living and to produce more employment opportunities, we must re-orient our national economic objectives and strategy. We must build new areas of comparative advantage, put the emphasis on manufacturing industries, and develop an aggressive technological strategy to promote economic

and social innovations. (Given the inherent weaknesses of the manufacturing sector of the Canadian economy, this change in emphasis is essential even if we go on increasing the rate at which we exploit our resources.) Canada needs a new National Policy adapted to the world environment of the next decades. For the first time in our economic history we must become an innovative nation.

In its recent study on the innovative performance of Canadian industry[9], the Science Council of Canada identified incipient stagnation of Canadian manufacturing industry in terms of output, employment, and profitability. The Committee heard the same story many times at its own hearings. This condition is directly reflected in the decline of industry's R&D expenditures in 1970 despite more generous fiscal incentives from the federal government.

The salient problem of Canadian manufacturing industry is its "stunted" development; it is limited to the scale of the Canadian market and it is excessively dependent on imported technology. The growing concentration of industrial power in foreign trans-national corporations could seriously curtail the expansion of Canadian-based industry.

The recent crisis may have the beneficial effect of awakening us all to these inherent difficulties and of forcing us to take effective steps to overcome them before it is too late. For long-term viability, Canadian manufacturing industry will have to cope with progressive sophistication of products, automation of production, diminishing tariff protection, and increasingly keen competition in both domestic and international markets. And that competition is not always a contest of price. More and more it is a battle of innovation in which technical superiority is a major weapon. Even in so-called "low-technology" products, innovations aimed at reducing costs and improving design can be very important. No firm or nation is likely to have any inherent or permanent monopoly in this, and leadership can only be established by specialization and the exertion of a continuing effort to keep ahead.

In Chapter 12 we described Vernon's Product Cycle theory which indicates how even smaller industrial nations might exploit the "dynamic comparative advantage" arising from technological innovation despite the handicap of a small domestic market. J. L. Orr has shown how Canada, like some other nations, might employ technological innovation as a means of promoting specialization to achieve market leadership and thereby create a viable and competitive manufacturing industry.[10]

Technologically-based industries can be promoted in Canada on the model of the Japanese, the Swedish, the Dutch, and the Swiss development

of enterprises capable of competing in the world trade league. Unfortunately, Canadian industry has not yet displayed much interest in doing so, due apparently to both structural and environmental deficiencies.

The Committee strongly believes that new product and process development offers a most promising and practicable means of expanding employment, increasing productivity and profitability, widening export markets, and generally realizing the full economic potential of our manufacturing industry. Thus the promotion of technological innovation in manufacturing industry should become a major objective of government policy. The need for substantial investments for this purpose becomes greater as the pace of the international technological race quickens and as the traditional advantages on which this sector of the Canadian economy was based in the past are progressively eroded. Such investments will call for innovations in the structure of industries and in the role of the financial community.

In this chapter, we examine the relationship between economic growth and technological innovation and the role of R&D in the innovation process. We propose a specific target for industrial R&D to correct the present innovative weakness of Canadian industry. And we consider the current private environment for industrial innovation and make concrete recommendations to improve it.

TECHNOLOGICAL INNOVATION AND ECONOMIC GROWTH

Over the decade of the 1960s considerable effort has been devoted to improving our understanding of the nature of technological change and its relation to economic growth. We have grown aware of the very large constellation of factors that underlie the process of economic growth, many of which are technology-related. For industrialized countries, part of the growth in the total volume of production obviously comes from increases in the sheer physical *quantity* of resources used—from increases in the number of people added to the labour force and to the volume of capital employed. But it is also evident that a large part of the growth in Western economies has come from improvements in the *quality* of the resources used, such as technologically advanced capital equipment and a higher level of education in the work force. In addition, there have been large increases in the *efficiency* with which these resources have been used; for example, through shifts of men and capital from less productive to more productive lines of activity, and through economies of scale and specialization.

Taking the Western world as a whole, it appears that somewhere between two-fifths and three-quarters of all economic growth—varying from country to country—results from quality improvements and efficiency factors, that is, from sources other than mere growth of labour, capital, and other productive inputs.[11] Of this increase in the quality of productive resources and the efficiency of their use, it is apparent that a large part is technology-related; but how much we cannot say with any degree of precision. However, we do not need precise measurements to know that the innovative process is the central bridge linking scientific and technical knowledge to production and use. Among expert observers who have made this point is Sir Alec Cairncross of Oxford University: he insists that ". . . technological change has been the mainspring of economic and social progress over the past two centuries, and . . . it remains the chief source of our increasing affluence."[12]

In its Fifth Annual Review, the Economic Council placed great emphasis on the innovative process, through which scientific and technological knowledge are brought into production and use. In part, the council said:

> While R&D is concerned essentially with invention—with the conception of an idea, and the initial development of the idea—innovation is concerned with the crucial role of entrepreneurial decision-making and risk-taking in the "follow-through" process, which involves the coupling of the initial idea or the results of R&D with engineering, design, financing, tooling-up, production and marketing. *Thus R&D by itself may add nothing to economic growth. It is the innovation process—beginning when management decides to move from R&D into engineering, design and all of the succeeding stages—which brings new products, processes and services into use, and which contributes to growth.*[13]

The Science Council too has placed heavy emphasis on the innovative process as the critical link leading to the effective application of scientific and technological knowledge:

> . . . the application of science and technology will make significant contributions to the solution of economic and social problems in Canada and in so doing will contribute to the realization of the goals of the nation. In order to have this happen, changes are necessary. In particular, more emphasis in future must be placed on development and innovation—on using science and technology to produce new or improved goods and services—and more research and development must be done close to the point where innovation will be initiated.[14]

From the emphasis given by these two councils and others to the process of innovation, it might be inferred that research and development activity are

not so important, specially since most of the productive technology Canada uses has in fact been imported. The Economic Council itself concluded, however, that "Canada cannot rely entirely on imported technology; there must be a strengthening of the country's own capabilities".[15] It put forward three arguments for strengthening our indigenous innovative efforts: it is necessary if we are to maintain our own scientists and engineers; it is necessary if we wish to achieve leadership in any area of modern science-based industry; and it is necessary if we wish to participate at the forefront of the fastest growing areas of world trade.

Thus, technological innovation is recognized as an important determinant of economic growth—and indeed the whole history of the growth of industrialized nations shows this—and there is a strong consensus that the low innovative capacity of Canadian industry (*described in Chapter 6, Volume 1*) must be radically improved if Canada's economy is to grow at the desired rate and if less reliance is to be placed on exports of raw materials and primary products to achieve that goal.

Even when, at some future time, Canada enters a condition of equilibrium or low growth—the "zero growth" condition mentioned in Chapter 11—considerable innovation will still be needed. One manager of a high technology firm said recently that "Zero growth does not mean zero innovation"[16] and another participant in that workshop mentioned a manufacturing plant that had to operate under zero-growth conditions: "We found that it took a lot more innovative management to run that zero-growth plant than it did for plants that were growing normally."[17]

In the whole spectrum of investment expenditures, the funds devoted to technological innovation may have the highest multiplier effect on economic growth and the standard of living. The direct technological multiplier effect is great because the innovative country usually has a seller's market for several years during which it can build substantial export sales and consolidate its position when competition develops through imitation or licensing to producers in other countries. What is more, investment in innovations has a large indirect technological effect in other enterprises and sectors. Professor James B. Quinn of Dartmouth College has summarized this point:

> . . . in stimulating long term growth, policy makers must recognize that the driving force is not investment itself, but the technological multiplier that innovation can achieve; (1) by increasing the productivity or value added of the sector in which it is employed, (2) by lowering the factor costs of those who utilize the output of that sector and releasing their resources for other useful purposes, and (3) by stimulating "responsive innovations" in customer, supplier or functionally competitive branches.[18]

The evolution and exploitation of a high national innovative capacity depends to a large extent on an adequate level of effectively managed indigenous R&D activity (concentrated mainly in industry), complemented by an efficient monitoring system on technical progress abroad and on technological forecasting.

INDUSTRIAL R&D AND INDUSTRIAL GROWTH

Many studies have been made in recent years (mainly in the United States) on the relationships between R&D leading to economic innovations and various indicators of industrial growth. One of the most comprehensive recent reviews of these surveys has been written by William N. Leonard, professor of economics at Hofstra University, who concludes:

> Research intensity, measured by company R&D spending, relates significantly to growth rates of sales, assets, net income, and other variables of sixteen industries performing nearly all manufacturing activity. The relation appears two years after R&D spending and increases thereafter.[19]

Other findings in Leonard's article deserve to be quoted:

> Efforts to estimate the rate of return to investment (both private and public) in R&D, though crude, have yielded impressively high figures, indicating that both important internal and external economies result from the investment.[20] An alternative hypothesis that causality ran from growth of industrial output to research intensity measured by company funds or manpower could not be sustained. . . . The analysis confirmed the significant influence of R&D intensity, measured by company funds or company-financed scientists and engineers, upon the rate of growth of real output.[21]

These findings, based on numerous empirical observations and reviewed by such well-known experts as Edward F. Denison, Robert J. Gordon, Edwin Mansfield, Howard Kitt, Thomas J. Hogan, and Marcel Tenenbaum, definitively confirm that at least in the U.S., internal R&D activities leading to market-oriented technological innovations are a significant source of expansion and profitability for individual firms and, therefore, of national economic growth, when efficiently organized.

It must be admitted, however, that there are substitutes for indigenous R&D aimed at invention and original innovation, viz., the rapid transformation of imported technology into innovations and the use of R&D for the improvement of inventions already made elsewhere—that is, R&D in support

of an absorptive strategy. Professor Quinn describes the Japanese experience, which has been most successful in this respect:

> Teams of Japanese executives and engineers have been sent—with combined company and government support—all over the world to visit the most advanced plants in their fields. These knowledgeable men, completely equipped with cameras and interpreters, thoroughly investigate the production and management techniques of their hosts. They look for non proprietary techniques which can be adapted to their own unique cost, facilities, organizational, and product structures. In addition, they seek out proprietary knowledge they can acquire under license arrangements.
>
> If a license is desired, a complicated negotiation is likely to ensue. Licensors claim they must first undergo several levels of hard bargaining within the Japanese company seeking a license. Then the license arrangements must be approved by the government's Ministry of International Trade and Industry (M.I.T.I.). The Ministry, which must approve all technology arrangements between Japanese companies and outsiders, is also reportedly a hard bargainer in the company's interest. Foreign patent representatives report that "negotiations may take months, but once approved things move fast. Payments are always made on time. And all contract terms are meticulously honored."
>
> Japanese companies—unlike those of many countries—have not been worried about the so called "prestige" of internal invention. Many international companies with Japanese licensees report that the latter actively adopt the technologies they license. (Reportedly, other nationalities frequently license "for access" to technology, but essentially develop their own approaches to the technology covered by the license.) This aggressive search for—and utilization of—foreign technologies has worked very well for the Japanese. Although Japan has had very restrictive policies about foreign ownership of Japanese business, it has been able to obtain the foreign technologies needed for its remarkable recent growth. In turn, the capital formation rate and skill buildups permitted by these technologies now offer a base for Japan to do more R and D itself and to export its own inventions in fields where it has previously been a net technology importer.[22]

This is saying, in effect, that it is necessary to have the capacity not only to conduct R&D leading to innovation but also to make innovations by applying R&D to imported technology. This point has recently been stressed by Sir Alec Cairncross: "It is an axiom that most inventions are made abroad. No country need limit itself to using its own inventions since it can licence or improve on inventions made elsewhere." The implication is that no industrial laboratory can be isolated and self-sufficient; this point has been well made by Dr. D. A. Chisholm, president of Bell-Northern Research:

> The industrial laboratory's function is an information processing machine. It couples in information, it authenticates information, it completes a package and then reformats it for a user, a factory or customer. Thus like a complex

circuit, it has an information flow and like a circuit, each part must be impedance matched to the adjacent elements.[23]

In reality there is a limit to the importation of technology because technology, unlike the scientific pool of knowledge, is not available through publications and scarcely accessible through personal contacts. This may delay innovation in the country importing the new technology to the point where it comes too late onto the market. Advanced countries are more conscious than before of the fact that technological progress is an important stake in the international trade race. The Japanese themselves (according to their Science and Technology Agency) are finding out that ". . . it is getting more and more difficult to have an easy access to excellent technology . . ." and that ". . . it is necessary to develop our own technology, which is the basis for competitive power . . .".[24] Canada too has experienced the serious limitations of imported innovations that could only be used within the confines of our domestic market, as Professor Harold Crookell has noted.[25]

In a growth strategy, innovation is the key factor and being overly dependent on importation is a poor substitute, particularly if the domestic market is small or not sufficiently protected or both. It may be cheap to import inventions and new technology provided they can be quickly transformed by the importing country, and Canada should certainly be more aggressive in this area. But there is a limit to this process, which will offer fewer opportunities as the international technological race gains momentum. In the final analysis, indigenous R&D expenditures are essential both to assimilate imported technology and to sustain a dynamic innovative capacity.

TARGET FOR INDUSTRIAL R&D

The international comparisons we presented in Chapter 6, Volume 1 showed that in 1967, Canada spent only 39 per cent of its national R&D effort on technological development and that the business enterprise sector performed *only 38 per cent* of the total R&D activities. The comparisons indicated that these two percentages were the inverse of the practice in other advanced countries. They also revealed that the Canadian government funded only 18 per cent of the cost of the industrial R&D performed by business, which was a much lower proportion than in several other advanced nations, including the United States (53 per cent), France (42 per cent), and Britain (35 per cent). Another special feature of the Canadian scene was that the government sector was a substantially larger performer of R&D than in most other countries.

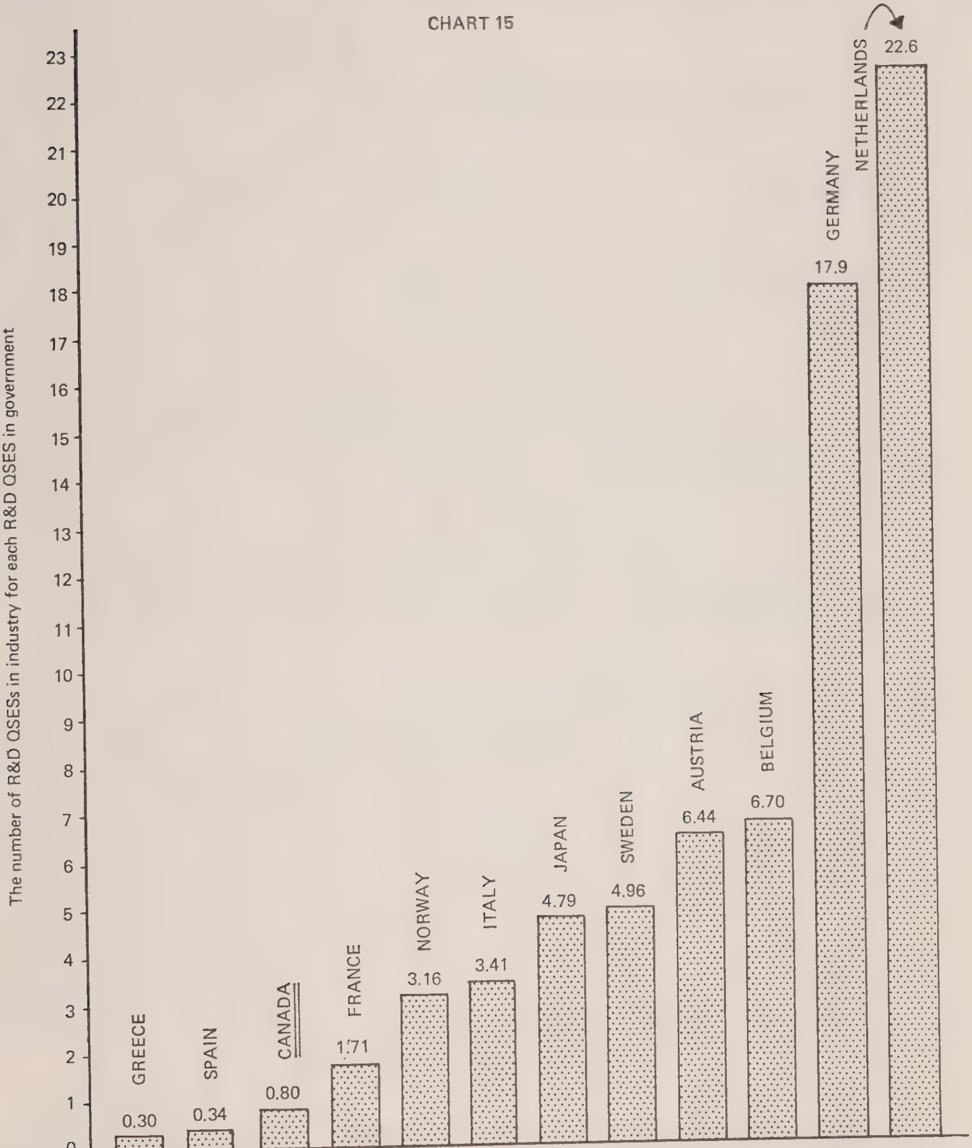
A similar imbalance is found in comparisons of the number of people working in R&D. The OECD report indicated that the innovative ability of a nation's industrial sector is related, not to the total number of qualified scientists and engineers (QSEs) conducting R&D in industry, but to the number of QSEs *plus supporting staff,* (QSESs). Figures for the total number of QSESs *conducting R&D* in Canada show that the Canadian government has a disproportionately high number of QSESs and, second, that the number of QSESs in the industrial sector is proportionately lower than in the industrial sectors of some other countries.

The first point is illustrated by chart 15, where it may be seen that for every QSES conducting R&D within the Canadian government there is less than one QSES conducting R&D in the industrial sector. By contrast, German industry employs 18 QSESs in R&D for every one in government. For the Netherlands the corresponding number is 23, for Sweden about 5.

The second point can be illustrated by comparisons with Sweden, Belgium, and the Netherlands. Although Sweden's population is only two fifths of Canada's, the total number of QSESs conducting R&D in Swedish industry is 25 per cent *higher* than in Canada. With less than half of Canada's population Belgium comes within 12 per cent of the number of QSESs conducting R&D in Canadian industry. Industrial R&D QSESs in the Netherlands, which has about three fifths of Canada's population, outnumber those in Canada by almost two-to-one.

A study by Dr. Peter Meyboom for the Department of Finance,[26] partly based on the 1969 Directory of Research Establishments in Canada prepared by the Department of Industry, Trade and Commerce, and a survey by Statistics Canada together provide more detailed measurements of the weakness of Canadian business in the performance of R&D. Table 18 shows research intensity as measured by R&D expenditures per $100 of sales, by industry and sales size group in 1967, for all of the 742 companies reporting R&D expenditures. We find that small firms display a surprisingly high ratio of 14 per cent, due mainly to small textile firms and small non-manufacturing companies. This group includes 125 firms and represents about 17 per cent of all companies reporting R&D activities. The ratio for all other groups varies inversely with sales size, from 2.1 to 1.0 per cent. The average research intensity for all Canadian firms performing R&D was only 1.2 per cent of sales, whereas U.S. manufacturing industry performed an overall research intensity of 4 per cent of sales (1967 figures).[27] In other words U.S. industry spends more than three times what Canadian industry spends.

CHART 15



Qualified scientists, engineers and supporting staff (QSESs) conducting R&D: a comparison between industry and government for 1963-1964

SOURCE: A Study of Resources devoted to R&D in OECD Member countries in 1963/64, Vol. II, OECD, Paris, 1968, pp. 54-55.

Table 18—Research Intensity as measured by R&D Expenditures per $100 Sales by Industry and Sales Size Group, 1967, for 742 Companies Reporting R&D Expenditures

<table>
<tr><th rowspan="2">Industry</th><th colspan="5">Sales Size Group[1]</th><th rowspan="2">Total</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>1. Mines</td><td>—</td><td>2.9</td><td colspan="2">0.8</td><td>1.1</td><td>1.1</td></tr>
<tr><td>2. Gas & Oil Wells</td><td>—</td><td colspan="3">1.1</td><td>—</td><td>1.1</td></tr>
<tr><td>MANUFACTURING:</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3. Food: Beverages</td><td colspan="2">1.0</td><td>0.3</td><td>0.3</td><td>0.2</td><td>0.3</td></tr>
<tr><td>4. Rubber</td><td>—</td><td>0.9</td><td colspan="3">0.5</td><td>0.6</td></tr>
<tr><td>5. Textiles</td><td>32.2</td><td>1.1</td><td colspan="3">1.3</td><td>1.4</td></tr>
<tr><td>6. Wood</td><td colspan="2">5.7</td><td colspan="3">0.2</td><td>0.5</td></tr>
<tr><td>7. Furniture & Fixtures</td><td>—</td><td colspan="2">0.6</td><td>—</td><td>—</td><td>0.6</td></tr>
<tr><td>8. Paper</td><td>—</td><td>0.8</td><td>0.7</td><td>0.6</td><td>0.5</td><td>0.6</td></tr>
<tr><td>9. Prim. metals (ferrous)</td><td>—</td><td>—</td><td>0.5</td><td>—</td><td>0.4</td><td>0.4</td></tr>
<tr><td>10. Prim. metals (non-ferrous)</td><td colspan="2">2.6</td><td>1.4</td><td colspan="2">1.0</td><td>1.1</td></tr>
<tr><td>11. Metal fabrication</td><td>12.0</td><td>0.8</td><td>0.6</td><td colspan="2">0.2</td><td>0.5</td></tr>
<tr><td>12. Machinery</td><td>12.7</td><td>1.4</td><td>1.3</td><td>—</td><td>1.1</td><td>1.3</td></tr>
<tr><td>13. Aircraft & parts</td><td colspan="2">3.6</td><td>9.6</td><td>—</td><td>7.3</td><td>7.4</td></tr>
<tr><td>14. Other Transport equipment</td><td>12.3</td><td>1.4</td><td>0.8</td><td colspan="2">0.1</td><td>0.1</td></tr>
<tr><td>15. Electrical products</td><td>10.8</td><td>3.5</td><td>2.0</td><td>5.0</td><td>7.1</td><td>5.2</td></tr>
<tr><td>16. Non-metal minerals</td><td>6.5</td><td>0.7</td><td colspan="2">0.7</td><td>—</td><td>0.7</td></tr>
<tr><td>17. Petroleum products</td><td>—</td><td>—</td><td>—</td><td colspan="2">0.7</td><td>0.7</td></tr>
<tr><td>18. Drugs & medicine</td><td>6.0</td><td>3.3</td><td>5.1</td><td>—</td><td>—</td><td>4.3</td></tr>
<tr><td>19. Other chemical products</td><td>5.6</td><td>1.8</td><td>1.3</td><td>2.0</td><td>2.4</td><td>2.0</td></tr>
<tr><td>20. Scientific Prof. Instruments</td><td>10.2</td><td>7.3</td><td colspan="2">4.9</td><td>—</td><td>5.5</td></tr>
<tr><td>21. Other manufacturing</td><td>4.2</td><td>0.7</td><td colspan="3">0.5</td><td>0.6</td></tr>
<tr><td>TOTAL MANUFACTURING</td><td>10.5</td><td>2.0</td><td>1.6</td><td>1.4</td><td>1.2</td><td>1.4</td></tr>
<tr><td>22. Transport & Utilities</td><td>—</td><td colspan="2">0.2</td><td>—</td><td>0.1</td><td>0.1</td></tr>
<tr><td>23. Other non-manufacturing</td><td>46.8</td><td>3.6</td><td>—</td><td>—</td><td>—</td><td>11.2</td></tr>
<tr><td>Total</td><td>14.0</td><td>2.1</td><td>1.5</td><td>1.3</td><td>1.0</td><td>1.2</td></tr>
</table>

SOURCE: Dominion Bureau of Statistics: Special Study, 1970.
[1]Sales Size Groups: thousands of dollars
1: 1-999; 2: 1,000—9,999; 3: 10,000—49,999; 4: 50,000—74,999; 5: 75,000 and over.

A recent OECD survey found that "73% of R and D projects . . . cost less than about $120,000" and that " . . . the probability of R and D expenditures leading to a commercially successful product varies between 8 and 35%",[28] while Professor Leonard's finding was that it usually took two years for a project to yield its first results.

These observations permit one kind of assessment of the innovative capability of Canadian industry. If it is assumed optimistically that the probability of R&D expenditures leading to a commercially successful product is 50 per cent rather than somewhere between 8 per cent and 35 per cent, a firm would need a minimum of two "normal" projects to have one successful innovation every two years, which would—again optimistically—require an annual R&D budget of at least $120,000. Even in the light of these optimistic assumptions it can be deduced from the DBS survey that, of the 742 Canadian firms reporting in 1967, most of those with sales below $10,000,000 a year would have R&D budgets beneath this minimum level and could not, therefore, be expected to be very effective at producing commercially successful innovations. Although this calculation is crude, the Committee thinks it very suggestive of our predicament.

Another criterion for appraising the adequacy of industry's R&D is the number of qualified scientists and engineers employed by individual firms. Lord Blackett, former president of the British Royal Society, has observed:

> One Q.S.E. [qualified scientist or engineer] in a firm may be useful for a little trouble shooting, reading the literature, etc., but little else. A group of, say, 5 Q.S.Es. might be considered a minimum for productive R. and D. effort, and so to a good morale in the group.[29]

An analysis of the size of research staffs in Canadian industry, based on the Directory of Research Establishments in Canada for 1969, is detailed in Table 19 and summarized in Table 20.[30] If Blackett's criterion of five QSEs is accepted, 375 establishments, or 57 per cent of the total, were below the critical mass. A more detailed examination of the directory indicates that 121 of those firms employed only two QSEs. On the other hand, the "Big Ten" companies employed 28 per cent of all QSEs engaged in industrial R&D.

In contrast to Leonard's findings for the United States, Professor Steven Globerman of York University concludes his survey of the relationship between R&D and industrial growth in Canada by stating:

> A study of fourteen industry groups performing the bulk of all industrial R&D in Canada, failed to provide any evidence of a significant relationship between the research intensity of an industry and the subsequent growth experience of that industry.[31]

Although Professor Globerman's findings may have been affected by the particular conditions of the period reviewed, 1959-61, his conclusion may well be valid just the same.

Table 19—Number of Industrial Research Establishments employing indicated number of QSEs

Industry	Number of QSEs per Establishment					
	<5	5–10	11–20	21–100	>100	Total of Establishments
Mines	5	1	2	1	—	9
Gas & Oil Wells	6	3	2	1	—	12
MANUFACTURING:						
Food & Beverages	35	15	4	1	—	55
Rubber	6	5	2	1	—	14
Textiles	3	3	1	1	—	8
Wood	3	4	—	1	—	8
Furniture & Fixtures	2	—	—	—	—	2
Paper	7	8	2	4	—	21
Prim. Metals (ferrous)	3	1	2	3	—	9
Prim. Metals (non-ferrous)	8	5	5	3	—	21
Metal fabricating	24	4	2	—	1	31
Machinery	48	13	1	3	—	65
Aircraft and parts	3	—	2	3	2	10
Other Transport equipment	5	2	1	—	—	8
Electrical Products	59	19	3	7	5	93
Non-metal Mineral products	21	5	1	—	—	27
Petroleum Products	4	1	4	2	—	11
Drugs & Medicines	15	10	3	2	1	31
Other Chemical products	54	30	9	13	—	106
Scientific and Professional Instruments	17	7	3	4	1	32
Other Manufacturing	20	7	1	2	—	30
Transport & Other Utilities	1	1	—	—	—	2
Other non-manufacturing	26	19	5	5	—	55
Total of Establishments	*375*	*163*	*55*	*57*	*10*	*660*
Percentage	*57*	*24.5*	*8.5*	*8.5*	*1.5*	*100*

SOURCE: Department of Industry, Trade and Commerce, 1969.
Directory of Research Establishments in Canada.

Different attitudes seem to prevail in the American and Canadian business communities. On the basis of Leonard's conclusions, it appears that American industry looks at R&D activities as an independent parameter and as a dynamic source of economic growth and profitability; and this is probably equally true of other innovative nations. In contrast, according to the evidence presented to the Committee, many segments of Canadian industry view research intensity as a passive factor determined by the climate for economic devolopment and sales. Perceived in that context, R&D tends to become residual and to be a result rather than a cause of growth. While the Committee agrees that the country needs a favourable economic climate to innovate, we are con-

cerned that Canadian industry may not become as innovative as it should be if it waits for increased sales of its traditional lines of goods before it decides to intensify its R&D effort and develop new processes and products.

Table 20—Summary of QSEs in all Industry Groups

Range of QSEs	No. of Firms	%	No. of QSEs	%	Average No. of QSEs
<5	375	57	863	13	2
5–10	163	24.5	1092	16.5	7
11–20	55	8.5	801	12	15
21–100	57	8.5	2010	30	35
>100	10	1.5	1904	28.5	190

SOURCE: Department of Industry, Trade and Commerce, 1969.
Directory of Research Establishments in Canada.

Professor Globerman offers three plausible explanations for the difference between Canada and the U.S. in the relationship of industrial R&D to growth and finds empirical evidence to justify at least his third hypothesis:

> One striking difference in the nature of the industrial R & D effort between the two countries is the scale of expenditures. Canadian industrial research intensities are almost always uniformly lower than the research intensities of their U.S. counterparts. ... This could be significant to the extent that the relationship between research intensity and growth is not uniformly linear over the range of expenditures in the two countries. Another difference exists in the sources of the R & D performance. A much greater percentage of Canadian industrial R & D is performed outside the user firm than is the case in the U.S. Other things being equal, one would expect a dollar of R & D performed within the firm to be more productive than R & D performed outside the firm since greater co-ordination between R & D personnel, production supervisors and management is possible with intramural R & D. . . .
> The effects of production scale are linked to the effectiveness of R & D, and they provide a strong a priori explanation of why the observed relationship between R & D and industrial growth seems to differ between the U.S. and Canada.[32]

These observations confirm the conclusions derived previously from Meyboom's analysis. Industrial R&D expenditures, like many other types of outlays, conform to the laws of increasing and diminishing returns. Below a certain minimum, they are largely wasted—if they are expected to be

useful for more than "a little bit of trouble shooting." As they rise above a minimum critical level, they bring increasing returns up to a certain maximum. But after that stage, if they continue to rise, the returns begin to decrease. The OECD has suggested that, in most cases, the research intensity ratio should not go beyond 10 per cent of sales.[33] The figures in Table 18 indicate that in 1967 most of the industrial groups in Canada were far below this maximum ratio; perhaps, even, so low that they were largely useless for innovation.

Whether we use international or domestic criteria, we cannot escape the conclusion that the Canadian business sector is desperately weak as a performer of R&D. And yet it is precisely in this sector that R&D activities in support of technological innovation should mainly be located. Thus, so long as economic growth remains important for our society, and particularly if Canadians decide to place less reliance on the rapid depletion of their natural resources to sustain their economy, Canada will have to participate much more effectively than it has done up to now in the growing international technological race. This will mean that a much larger share of a substantially enlarged total R&D effort will have to be performed by the business enterprise sector on development activities leading to innovations.

The allocation of R&D effort between performing sectors for the main industrialized countries in 1967 was given in Volume 1 (*Table 5, Chapter 6, page 128*). The business sector performed 65 per cent or more of total R&D in six of the nine countries that were compared with Canada. Only Japan, the Netherlands, and France were below that figure, in the range 54 to 62 per cent, and it is now a matter of national policy in these countries to increase that proportion. On this basis it is clear that the portion performed by the industrial sector in Canada, which was only 38 per cent in 1967 and had dropped to 37 per cent by 1969, should be increased as rapidly as possible. It is certainly not extravagant to suggest, as a target, that it should reach 60 per cent by 1980.

This proposed target will obviously require a drastic reallocation of the national R&D effort between the three major sectors of performance, industry, government, and universities. In 1969, industry's expenditures on R&D totalled $390 million. On the basis of a projected gross national product of $190 billion and 2.5 per cent of GNP devoted to total R&D activities in 1980, expenditure in the business enterprise performance sector would then amount to about $2.9 billion *in current dollars.*

However, our forecast of GNP in Chapter 13, based on projections prepared by OECD, assumed 3 per cent annual inflation. Our target for in-

dustrial R&D *in 1969 dollars* would be approximately $2 billion, slightly more than five-fold the 1969 figure, implying a real growth rate on the order of 16 per cent per annum. It should also be noted that our proposal does not take into account the "sophistication factor", the increasing cost of R&D activities as they become more complex and require more sophisticated techniques and equipment.

The Committee recommends, therefore, that the R&D activities performed by the industrial sector be substantially increased so that by 1980 they represent a maximum of about 60 per cent of the national R&D effort.

The proposed target could considerably improve the return on expenditure by enabling a much greater number of Canadian firms to attain the critical size of research team required to obtain useful results. This qualitative and quantitative improvement in the R&D performance of the business enterprise sector is an important element in what we foresee as a gradual, but eventually radical, change in the structure of Canadian industry, in a substantial rise of Canadian technological innovations, and in a sounder basis for rapid economic growth and increasing standards of living, while freeing us from the necessity of rapidly depleting our natural resources. Thus, the suggested increase and re-direction of R&D expenditures might well prove to be the best investment available to Canadians in the 1970s.

The target appears reasonable not only in the light of external comparisons but also for internal reasons. It is essential if the industrial R&D effort is to reach the phase of increasing returns. It is realistic in terms of its manpower requirements. Indeed, if it were not attained and present trends in university enrolment continue into the 1970s a serious surplus of QSEs will develop. The Committee has to recognize, however, that the objective is not realistic if one considers only the recent trends in the performance of R&D by Canadian industry. In 1970, the value of R&D activities performed by the industrial sector increased by less than $2 million over the total of $390 million reached in 1969, in spite of a rise of $30 million in government financial support, and probably this situation has prevailed in 1971 too.

How can we account for this recent decline in R&D funding by industry? Economic conditions have certainly exercised a definite influence. There should be a direct correlation between R&D funding by the private sector and the overall level of economic activity, so that the 1970-71 recession would partly account for the reduction. Uncertainty about the public environment for innovation, including taxation and other government policies, also had a

negative impact. We believe, however, that the industrial sector may have reached a plateau as a source of R&D funding for more fundamental and structural reasons.

If improvements are made in the public and private environments, Canadian industry will be in a position to increase its R&D and innovation effort gradually but substantially on its own and the objective will be achieved by 1980 without any significant increase in the relative share of government funding of industrial R&D, although, as we will suggest, the form of direct public support will have to be drastically changed. Our confidence is supported by the experience of Britain in the early, successful phase of its industrial revolution, which the historian Samuel Lilley has contrasted with less successful attempts made in continental Europe:

> [In] contrasting the British position with that of her rivals—[one notes] inventors on the continent failing only for lack of financial backing; an aristocracy standing aloof from and despising the world of commerce and industry; avenues of advancement for ambitious members of the middle classes still confined to the traditional learned professions; industry regarded as socially degrading and therefore left in the hands of the second best; and so on. And finally one would contrast the extent to which continental industry was bound by government regulation and guild control with the comparative freedom of its British counterpart. . . . The state-supported industries [on the Continent]—intended as forcing houses of industrialisation—were in practice stunted by bureaucratic inefficiency. . . . the Director of a French state industry showing that a revolutionary technique would work, [but] small-scale English and Scottish firms developing it in practice—is a fair symbol of the contrast.[34]

THE CANADIAN PRIVATE ENVIRONMENT

If the Committee's proposed target for industrial R&D is to be achieved by 1980 and if the suggested substantial increase in effort in this area is to produce a high flow of innovations that will permit us to re-orient and sustain the Canadian economy, the private environment surrounding the innovation process will have to be radically and rapidly changed in several respects. We will examine five main points: the business enterprise sector itself, labour mobility and the labour movement, the availability of private venture capital, the supply of QSEs for industrial R&D, and the management of industrial R&D and technological innovations.

The industry representatives who appeared before the Committee were highly critical of the public environment for innovation in Canada, including most of the Canadian government's industrial R&D incentive programs. They

said much less however, about the innovative capacity and performance of Canadian industry and what they could do themselves to improve it. To discuss this topic properly, a distinction must be drawn between secondary manufacturing mainly designed to serve the Canadian market, on the one hand, and primary manufacturing or resource-based industries, on the other. These two kinds of industry have quite different problems with innovation. Even the issues of foreign ownership and control as they affect innovation, which both kinds raise, are of quite different natures.

1. *Secondary manufacturing industry*

Many secondary manufacturing firms feel limited by the size of the domestic market and the declining share of the market that is available to them. They assert that if the Canadian market were larger and better protected against foreign competition, the flow of technological innovations and R&D activities they could afford to fund would increase substantially. This may well be true. But if these two conditions were the only possible solutions to the improvement of their innovative capacity, there would be ground for pessimism, because our domestic market is not going to grow rapidly in the short term and it is not realistic to expect higher protection in Canada unless the government finds it necessary to take new countervailing measures in response to protectionist initiatives such as the recent American actions. The firm belief of large parts of our secondary manufacturing sector that these two conditions are required is largely a survival of entrepreneurial attitudes generated by Sir John A. Macdonald's National Policy, initiated in 1879.

Mr. V. O. Marquez of Northern Electric Company Limited mentioned the prevalence of this old mentality when he stated that "... the problem in Canada is at least partly a matter of national attitude",[35] and went on to say that Canadian industry had developed "... the kind of mythology ... which says that industry can only be developed if it can be supported on a domestic base".[36] He illustrated his point: "One of our greatest competitors in our field, the L. M. Ericson Company in Sweden, gets 20 per cent of their business in Sweden. This is their point of view, this is the base from which they start. This never has been the base from which Canadian industry has started."[37]

Whatever the National Policy did in its time, it has not been very propitious for technological innovation, and in the long run it has created an atmosphere of false security that now threatens to bring some of these industries to a dead end. Top management here must change its philosophy and attitudes. It must forget the past and develop a new outlook and strategy aimed at improving innovative capacity. In the world of tomorrow there will be no other choice

for survival and expansion. After the Economic Council, the Science Council has also deplored the weakness of business management in Canada:

> There is unquestionably a need to improve the professionalism of Canadian management. In fact, if manufacturing industry is to grasp the new opportunities arising in this decade, it must totally review its existing management development programs.[38]

The Committee hopes that industry will hire a greater number of MBAs and be receptive to their new ideas, even if they require radical changes in the internal organization and structure of individual firms. Sound but radical change is precisely what is required. The business-as-usual mentality is clearly outdated.

The Committee is worried by reports of an "entrepreneur drain" from Canada. For instance, Dr. Donald A. Chisholm recently recalled that "they used to kid Canadians" in the U.S. because there were too many of them in U.S. management. Managers with effective entrepreneurial abilities are a precious resource needed by *all* sectors of society and Canada can ill afford to lose any. We hope that studies of entrepreneurship in Canada will be vigorously pushed by the Department of Industry, Trade and Commerce and that they will include an analysis of the drain, in particular of the role that parent companies of Canadian subsidiaries play in siphoning-off entrepreneurial talent from this country.

The innovation of new processes designed to reduce the cost of a product or improve its quality is not necessarily discouraged by the small size of the market. On the contrary, such innovations normally contribute to its expansion. A sufficiently large potential market is required for new products, but again, if this kind of innovation is not too expensive—and usually it is not—then a very large market is not required to make it profitable. Moreover, the empirical evidence gathered by the OECD suggests that there is a very low correlation between national innovative performance and the size of the domestic market (measured by GNP). Sweden, Switzerland, the Netherlands, and Finland are all strong technological innovators yet have small domestic markets. It is not so much the size and intensity of national demand that determines the success of the innovation, apparently, as the entrepreneurial, organizational, and technical resources within the country that are able to identify international needs. The OECD report concludes:

> Firms and countries that have these capabilities appear to be able to overcome tariff and non-tariff barriers, as well as the barriers of distance, differing legislations and standards, in order to respond to worldwide demands for technological innovation.[39]

Once the traditional domestic industries are convinced they can be as innovative as their counterparts in other countries, and that this is the only possible avenue of success in the future, they will quickly grasp the basic requirements of a new strategy. Changes in two complementary directions will be needed.

In most industries, mergers will be necessary. These will be easier to carry out if competition legislation is properly formulated and intelligently administered. Table 1 showed that nearly 60 per cent of industrial establishments reporting R&D activities in Canada—not to speak of those with no such activities to report—were beneath the minimum level suggested for efficiency although their research intensity, the ratio of R&D to sales, must have been above the maximum recommended by OECD, as indicated in Table 19.[40] This situation clearly establishes the need for mergers if R&D activities are to be more productive.

A second change is that it will be necessary for medium-sized and large firms to specialize much more than they did when the main aim was to concentrate on the Canadian market. The OECD notes:

> The most important environmental factor is the increasingly open—indeed worldwide—framework within which strategies for R and D and technological innovation must be conceived. This is not only because no one country can hope to produce all the scientific and technological knowledge relevant to innovation, nor only because markets wider than national markets may be increasingly necessary to amortise the fixed costs of launching innovations. It is also because increasing liberalisation and interdependence means that competition through technological innovation is conducted less and less within a national framework. ... Effective competition in international markets requires specialisation, and technology cannot be exempted from this requirement. ... In areas of rapid technological change, where new market opportunities are continually opening up, there are ample opportunities for specialisation within sectors—between different sorts of aircraft, different sorts of electronic goods, different sorts of drugs, or different sorts of transportation equipment.[41]

Thus, fusion or specialization or both and modernization constitute an essential prerequisite not only to increase productivity but also to build an innovative capacity in many segments of our domestic industries. This suggestion has been made time and again in Canada, although it has been justified more in terms of improved productivity than of greater innovative capacity. Nevertheless, it is recognized as the only condition of survival and progress in many

cases. For instance, Mr. Frank S. Capon of DuPont of Canada Limited mentioned this "problem of scale" in the Canadian chemical industry:

> In our industry, for example, we believe we do the best job in the world in making nylon . . . with full efficiency and with all the technology available on nylon, we have unit costs that indicate that our costs per pound of nylon are considerably higher than the costs in any other country because we cannot run one type of nylon day in and day out on one machine.[42]

Mr. Leonard Hynes, when president of Canadian Industries Limited, stated:

> Our return on investments over the past 20 years . . . has not been anything like good enough. We have, unfortunately maybe, talked people into putting money into the company but they should have put it somewhere else. For the future it is even worse.[43]

The problem of the chemical industry, it can be seen, is not new; it is only becoming worse. Mr. Capon pointed out to the Committee that one solution to the problem of scale would be to operate a single large nylon plant for all Canada. While there has been a good deal of talk about the need for horizontal integration in Canada, little has been done to solve the problem.

Industry spokesmen have blamed government tariff policy for creating the difficulty and anti-combines policy for preventing a realistic solution. Others, mainly in academic circles, have pointed to the lack of business leadership, while the labour unions have been attempting to move toward wage parity with the United States. One thing is certain: drastic steps will have to be taken soon to change the structure of secondary manufacturing industry radically, to reduce the number of firms, and to increase their size and their specialization. It will be too late in the 1980s to prevent its gradual extinction. We are already at a crossroad. While the recent unequal reduction in tariffs is forcing individual firms to specialize, the new direction they are taking may not be in the best long-term interests of Canada.

This problem is further complicated by the effects of foreign ownership and control on the number and size of firms, on industrial specialization, on innovative capacity, and on R&D activities.

One of our earlier conclusions (Chapter 6, Volume 1) was that foreign subsidiaries tended, under similar conditions, to perform more R&D activities in Canada than Canadian-owned companies, at least until recent years. It is also true that they have access to a large amount of proprietary technology owned by the parent company, as Imperial Oil Limited told the Committee:

> In general, it is our opinion that a degree of foreign ownership assists rather than hampers economically successful innovation in Canadian industry.

> It provides the broad, low-cost technological foundation essential for further Canadian research and innovation.[44]

There is obviously an important element of truth in this statement, which was repeated in different words by several other witnesses, although the company did not specify what it meant by "a degree of foreign ownership". But what if an industry is really dominated by foreign subsidiaries? The statement made by Imperial Oil does not tell the whole story.

In the sector of secondary manufacturing industries, most American subsidiaries came here to exploit the domestic market without paying tariffs. For some there was also the intention of benefiting from the Commonwealth preferential system. In consequence they were usually designed to follow, on a smaller scale, the production pattern of the parent company, though with inevitably lower productivity levels. The gradual erosion of the preferential system and its virtual elimination with British entry into the European common market, in addition to the increase in the number of American subsidiaries located in the United Kingdom and other Commonwealth countries, will substantially weaken the position of Canadian subsidiaries in the Commonwealth market. The reduction of Canadian tariffs has exposed them more and more to foreign competition. Even when their parent company allows them to sell in the American market, this permission cannot be very important as long as they cannot specialize and reduce their costs. How could they successfully compete in that market with their lower efficiency and American trade barriers? Thus, many subsidiaries established in Canada as replicas of their U.S. parent companies are being caught in a squeeze and have lost their original *raison d'être*. In the past they may have been useful extensions of American firms, but now they are more likely to become liabilities for those companies, especially if the U.S. initiates DISC and similar measures and no countervailing measures are taken in Canada.

These subsidiaries may still be in a position to compete with their Canadian counterparts, but they are also monuments to a policy instituted almost a century ago and their contribution to Canadian industrial fragmentation, weak innovative capacity, and relatively low productivity is becoming more evident. Their R&D effort has been declining. Moreover, as the Science Council notes:

> In the semi-autonomous subsidiary, R & D tends also to be semi-autonomous —typically, scaling-down production technology for the Canadian market, or technically adapting the product to Canadian tastes or climate. . . . most market research departments in subsidiaries take a narrow view of their potential role. They limit their activities to identification of those products produced by the parent firm which can be introduced in Canada.[45]

This is not a particularly impressive contribution to Canada's capacity to innovate. But basically these subsidiaries suffer from the same disease as Canadian-owned manufacturing firms. What both need is greater specialization, the development of a more aggressive innovative strategy along narrower lines and the introduction of successful technological innovations that can be exported to world markets. Will the parent companies in the U.S.A. allow their Canadian subsidiaries to carry out such fundamental reorganization? This is the crucial issue raised by foreign ownership. It would certainly be in the parent companies' interest to allow this conversion; in fact their best course would be to encourage it, because it is the only way their subsidiaries will ever be more profitable.

The Committee believes that this tactic should also become a major plank of the policy being developed to deal with the foreign ownership issue. This "Canadianization" of foreign subsidiaries would be made easier by a reduction in foreign ownership and control, which in turn might prevent the application of U.S. anti-monopoly legislation to subsidiaries in Canada. It would certainly contribute to easing the Americans' dollar problem.

We are convinced that secondary manufacturing—whether Canadian-owned or foreign-owned—is rapidly reaching a structural dead end. Canadians have been aware of this for some time. Nothing less than an industrial revolution will bring the necessary specialization, improve productivity, build up innovative capacity, and substantially increase the flow of successful technological innovations. While a national consensus has been reached on the nature of the crisis, the action taken to solve it has been timid and spasmodic.

While the debate on the foreign ownership issue has largely been carried on by two élitist groups, the "continentalists" in business and the "socialists" in universities, mostly in extreme terms, the two senior levels of government have fought over jurisdiction in economic policy, and neither has succeeded in developing a coherent and complementary industrial strategy. In the federal sphere, the Department of Regional Economic Expansion may be promoting a further artificial industrial fragmentation in its efforts to help underdeveloped areas. That at least is the fear of the Science Council:

> . . . when a government-subsidized industry, located in a less-developed province, further divides an already fragmented market . . . [the] intensified competition that results can harm, or even destroy, both the new company and long-established companies. In the long run, establishing non-viable industries does not provide employment, but simply moves unemployment from province to province.[46]

At the same time the Minister of Industry, Trade and Commerce has appointed a board of three to look into the consolidation of the textile industry. While this is a desirable objective in itself, the approach being followed does not seem to be particularly effective. Bringing in outsiders, two of them on a part-time basis, to solve a complicated problem involving a whole range of products and many technical difficulties is time-consuming and may unduly delay the practical solutions that are urgently needed. We believe that the problem of scale exists in most domestic industries; if this approach is followed in all cases, there will be no time to develop innovative capacity in the 1970s.

The Committee believes that the industrial revolution, if it is to come soon and produce tangible results, requires a special two-stage strategy.

In the first phase, the principle of participatory democracy should be used so as to benefit from the practical experience of both business and labour leaders who have had to live with the problem of scale for many years. They know best the complicated technical, managerial, and job adjustments that maximum efficiency will require in their industries. The early involvement of workers' representatives is essential because the major reorganization of an industry will have important implications for its labour force. Each major secondary manufacturing industry, with its immediately related sectors, would be asked to set up a task force and prepare a reorganization plan incorporating desirable mergers and product specialization schemes together with their employment and regional implications and the form of government assistance required.

The Minister of Industry, Trade and Commerce should take the initiative and should appoint an impartial full-time chairman and a small secretariat for each task force. The Committee feels that with the early retirement plans now in force in governments, industry, and universities, it would not be too difficult to find enough wise men to act as chairmen of these working groups. The role of the chairman and the secretariat would not be to direct and control the work of the task force but to make sure that it does its job on time and to help if requested. The plan proposed would be the exclusive responsibility of the task force itself and would be presented to the minister by the chairman along with his own reaction.

The first stage would offer several advantages. Many task forces could work in parallel. They could consult with each other on matters of common interest or grey areas and thus this large-scale national undertaking could be completed much more rapidly and effectively. Industry and labour could not complain that unrealistic programs had been imposed on them without proper

consultation. Canadian subsidiaries would have an excellent opportunity to show how they could fit better into the Canadian scene and make a greater contribution to the national objective of fostering technological innovations. Since the plans prepared by the private sector would be presented to public authorities more or less at the same time, they would provide both in detail and in broad outline a view of what has to be done in the whole sector of secondary manufacturing in Canada.

The second stage would consist of a government review of the plans in the light of the requirements of the public interest, particularly economic efficiency, innovative potentiality, and international competitiveness. These plans should come under the purview of competition policy only when they have been implemented. They should be examined, modified, and approved by a Cabinet committee under the chairmanship of the Minister of Industry, Trade and Commerce and composed of the President of the Treasury Board, the Minister of Regional Economic Expansion, the Minister of Consumer and Corporate Affairs, the Minister of Labour, and the Minister of State for Science and Technology. Before they are finally approved they should be submitted for consultation to the provincial governments immediately concerned.

To accelerate this review process and advise the Cabinet committee, an Office of Industrial Reorganization should be set up in the Department of Industry, Trade and Commerce. The chairmen and secretariat of the various task forces would be its members. These people would already know the nature and implications of the plans prepared by the task forces so they would be in an ideal position to give their advice to the ministers quickly. The Canadian Development Corporation should be closely involved in this examination.

The Committee therefore recommends:

1. That secondary manufacturing industries be requested by the Minister of Industry, Trade and Commerce to organize task forces, with proper labour representation, to consider the problems of scale and specialization and to prepare a plan within a year to improve the efficiency, the innovative capacity and the international competitiveness of individual firms through mergers or otherwise;

2. That the minister appoint an impartial chairman and a small secretariat to assist each task force;

3. That a special Cabinet committee be appointed under the chairmanship of the Minister of Industry, Trade and Commerce to examine, modify, and

approve, after consultation with the interested provinces, the plans prepared by the industrial task forces; and

4. That an Office of Industrial Reorganization, mainly composed of the chairmen and the secretariat of the task forces, be established to assist the Cabinet committee.

The Committee has come to the conclusion that this extensive, complex exercise in participatory democracy has become absolutely necessary if secondary manufacturing industry in Canada is to expand or even to survive. The success of this great collective undertaking would be one of the major objectives of a new National Policy.

2. *Primary manufacturing and resource-based industry*

The problems faced by our resource-based and primary manufacturing industries are quite different from those of secondary manufacturing. Here industrial concentration already exists in most cases. The basis for innovative capacity and international competitiveness has been generally established, at least for the products they now sell. However, the management of this sector also often suffers from a passive, business-as-usual attitude. Secondary manufacturing industries based their traditional strategy on the tariff protection of Sir John A. Macdonald's National Policy. Resource-based industries developed a sense of security from the favourable impact of the second technological revolution of the early 1900s and from the realization that they had abundant reserves and cheap power, and a growing demand for their products in foreign markets. Most of them, as a result, failed to innovate. Most neglected their R&D.

There is a growing feeling, however, that these industries are finding it increasingly difficult to expand along conventional lines. Several factors account for the new conditions. New technology is producing more substitutes for natural resources. Canadian costs are rising. New sources of supply are becoming available abroad and are competing more successfully with Canadian products. The revaluation of the Canadian dollar with the return to a floating rate has meant the loss of an advantage enjoyed for most of the 1960s.

While the aluminum and the pulp and paper industries, for different reasons, may experience long-term difficulties in expanding along conventional lines in Canada, the prospects for other segments of this industrial sector, specially the mining industry including oil and natural gas, are very bright indeed because of the increasing depletion of world resources. In terms of

overall and long-term Canadian interests, the problem of resource-based industry is not an inability to grow along traditional lines. The main problems are finding new ways to economize on resources and utilize wastes at the production stage, discovering new product uses, and processing primary products to a further stage in Canada before exporting them.

Unlike the secondary manufacturing sector, resource-based industries need no structural revolution to build up a base for innovation. Most of them already have it; they have simply not used it very effectively. Table 17 gives an idea of the R&D weakness to be filled for such industries as mines, gas and oil wells, paper, primary metals, non-metal minerals and petroleum products. Only one industry has an overall research intensity ratio much greater than 1 per cent, and for that one the figure is less than 2 per cent. This is far from the range of 4 to 10 per cent that appears to be effective. And yet there should be plenty of opportunities for these industries to use their innovative capacity on problems of the kind we have listed.

A major impediment to using their existing innovative capacity for national purposes is the high degree of foreign ownership and control in these industries. While Canadian subsidiaries in the secondary manufacturing sector are usually horizontally integrated with their parent companies, which is their major weakness, in the resource-based industries the subsidiaries have in most cases a vertical relationship to the parent companies, which raises quite a different problem. The output of such a subsidiary is an ingredient of the operations of the foreign parent rather than a small offshore copy of it. As long as they continue to serve the needs of their parent firms, however, there should not be anything to prevent subsidiaries developing their own capacity for R&D and innovation.

This leaves broad areas where there should be no conflict of interest; where, on the contrary, foreign companies should encourage their Canadian subsidiaries to become more innovative. They include improved productivity, cost reduction, the economizing of resources, and the utilization of wastes, to the extent that new resources are becoming scarce and that wastes can be used profitably.

There are at least two points on which interests are likely to diverge, however: finding new uses for the primary product, and especially further processing.

New uses the parent company is not interested in might divert the operations of the subsidiary to more profitable sectors, thus reducing the supply and increasing the price of the primary product that the foreign firm needs.

Further processing at the primary product site might be less costly, might weaken the vertical relationship that was the justification for the establishment of the subsidiary in the first place, and might ultimately create a successful competitor for the parent company. Here the interests of the foreign firm and of the country where its subsidiary is located must almost inevitably come into direct conflict.

On the face of it these two areas of conflict must seriously limit expansion of the subsidiary's R&D and innovative capacity and, as a result, its growth potential and its ability to compensate for the negative impact new technology can have on the demand for its traditional product. This aspect of the foreign ownership issue poses a real dilemma. On the one hand, the parent company provides an outlet well protected from competitors. On the other hand, it also prevents the subsidiary from developing a defensive and aggressive innovation strategy that could ensure its long-term survival or at least its more rapid and normal expansion and that could help it make the maximum contribution to the prosperity of the country where it is located.

This is the most difficult aspect of the foreign ownership issue. The maintenance of this kind of vertical integration is not in Canada's long-term best interests because, in theory at least, it reduces the innovative capacity and the growth potential of subsidiaries. On the other hand, it is unlikely that parent companies will voluntarily take steps to weaken relations with their subsidiaries. Since the private environment is not in this respect likely to improve on its own initiative, the issue of the further processing of primary products by Canadian subsidiaries becomes a matter of public policy. It is examined more fully in the next chapter.

When we look at the Canadian resource-based industries, Canadian-owned and foreign-owned, as a whole, we find their innovative basis is not utilized as much as it should be and that their R&D effort is relatively low. The Committee believes they should be invited to make a detailed examination of their own situation. They should start by getting the best possible projections of world reserves and requirements and of Canadian potential, then analyze the innovative and R&D performance of the industry and how it could be improved, both quantitatively and qualitatively, by individual companies themselves or through collective arrangements. They should include suggestions for government assistance, if necessary.

Here again, the usual pattern would be reversed. Industry would be asked to define its own problems and to look at what it can do for itself before asking for government assistance or blaming public authorities for inappropriate

action. In the process the difference in innovative and R&D performance between Canadian-owned and Canadian subsidiaries, if it exists, would come to light. The government would then be in a much better position to initiate incentive programs, specially in the areas where the innovative and R&D effort of Canadian subsidiaries is inhibited by vertical integration with their parent companies. These programs would be available to any firms, subsidiaries or Canadian-owned, although in practice only the Canadian firms would be likely to be free to take advantage of these inducements and to develop in conformity with Canada's long-term interests. If this approach were followed, the tangible results might be surprising.

The Committee recommends, therefore, that resource-based and primary manufacturing industries be requested by the Minister of Energy, Mines and Resources to organize specific task forces, with proper labour representation, to consider their innovative and R&D performance and within a year to prepare a plan to improve that performance in order to economize resources, utilize wastes more efficiently, reduce costs of production, discover new uses for their products, and further process these products in Canada for export.

The procedure to be followed here would be similar to that proposed for secondary manufacturing industries. The Minister of Energy, Mines and Resources would appoint an impartial chairman and a small secretariat to assist each task force and himself act as chairman of another special Cabinet committee composed of the same ministers, except that the Minister of the Environment and Fisheries would replace the Minister of Consumer and Corporate Affairs. The Cabinet committee, in co-operation with the provinces, would review the plans proposed by the task forces. A special office, similar to the proposed Office of Industrial Reorganization, would be set up to assist the Cabinet committee.

We are proposing a detailed examination of the basic weaknesses of the two major industrial sectors of the Canadian economy. We would like to see industry prepare plans to correct these weaknesses and we propose that the Canadian government, in co-operation with the provinces, review these plans and decide their policy implications. The Committee readily recognizes that this is a major and complicated operation. We are convinced, however, that such an examination has become absolutely necessary at a time when industry's very viability is being questioned. Industry must find itself a new vocation in the drastically changing world trading patterns of the last part of the 20th century. This essential operation cannot be done properly by any government,

parliamentary committee, or royal commission. It must be a collective undertaking starting within the private sector.

3. *Labour mobility and the labour movement*

The attitude of industrial workers and their leaders is an important element of the private climate surrounding technological innovation and the R&D effort funded by industry. Successful industrial R&D is not something wholly conducted by white-coated scientists and engineers. The skilled worker, the production line worker—all the men on the shop floor—have skills and insights required for innovation, even if they are seldom encouraged by management. Case histories illustrating the potential in the labour force were given by Professor Chris Argyris in a talk at the University of Toronto:

> Some forward-looking firms have begun to experiment with changes in the traditional assembly-line system. Their basic idea has been to find ways in which to put complexity and challenge back into the jobs. The Polaroid Corporation, for instance, has taken on workers with less than high school education and tried to educate them up to a level that equals a college-trained engineer's. Clerical employees have been permitted to work part-time in the research laboratories as technicians. In both cases the employees have responded enthusiastically and performance has been above average.
>
> Harwood Manufacturing, a Virginia firm which makes wearing apparel, has experimented with giving the employees more responsibility and authority to question work procedures and to influence production decisions and job designs. In one experiment, the company tackled the lagging production of a particular product by bringing the production workers in on discussions of the problem rather than turning it over automatically to the staff engineers. Several different approaches, in which differing degrees of responsibility were shared between production people and engineers, were tried. What worked best was turning the problem completely over to the employees, with the engineers acting as consultants rather than, as some workers put it, 'management hatchet men'. Changes in this direction have led to marked increases in quality and productivity at Harwood, as well as a reduction in employee turnover from 18 per cent to 6 per cent a year and a lowering of absenteeism from 17 per cent to 4 per cent a year. One manufacturing concern has gone so far as to rename itself after the introduction of its new approach to production. Non-Linear Systems, which makes electronic equipment, has abandoned assembly lines in certain areas in order to allow one person to assemble, say an entire voltmeter from start to finish. This may take up to three weeks, after which the employee personally tests the product. If the customer finds any difficulty with it, the meter is returned for correction to the employee who assembled it. Results include a 50 per cent reduction in man-hours devoted to building the instrument. At a deeper level, the employee's sense of responsibility and commitment has become very high.[47]

The training and re-training of the production force to cope with technological change is just as important for R&D and innovation as the training and re-training of scientists and engineers. Equally, it is clear that labour can prevent technical progress or delay innovations to the point where it is too late to introduce them successfully. In this area, the labour movement often faces a dilemma. On the one hand, the new world context is forcing Canadian industry to become more innovative in order to improve productivity, to sustain a strong economy, and to provide higher incomes and more jobs, and this for labour is the bright aspect. On the other, technological change and conversion of the industrial structure require a greater occupational and geographic mobility of the labour force. Moving from one job to another or from one locality to another always involves immediate sacrifices, even temporary unemployment or early retirement, for individual workers and their families, and this is the negative aspect of trying to produce a high flow of technological innovations. Should the labour movement make its important positive contribution to the task of industrial conversion and innovation, in other words, while trying to minimize its negative impact through appropriate arrangements with industry and compensatory action by governments? Or should it simply concern itself with better working conditions and wage parity policies, even, if apposite, opposing productivity improvement programs?

It is obvious that the climate of industrial relations is far from ideal in Canada at the moment. Management undoubtedly has its share of responsibility for this situation. But labour leaders must also bear part of the blame. Some of them have become social and political activists, sponsoring causes that are remote from the preoccupations of the workers. The image they project on television often reflects an inclination toward sensationalism rather than genuine social conscience. They appear to be in revolt against the entire economic and political system regardless of the fact that it seems, on the whole, to satisfy their constituents. In assuming the role of perpetual and destructive critics, as if economic and social conditions had never been worse, they have developed a credibility gap that is a disservice to their real grievances and prevents them from playing a positive role in improving social conditions. The Committee indicated earlier that some elements of Canadian business management would have to change their mentality if this country was to become a more innovative nation. The same observation holds for some segments of Canadian labour leadership.

More basically, it is our whole system of industrial relations and collective bargaining that should be seriously questioned. Production requires the

joint effort and co-operation of management, capital, and labour. But in our present system the distribution of the returns from production puts them in the position of competitors or even enemies trying to get the largest possible share of the plunder. There is an obvious contradiction between intimate co-operation for the production of wealth and aggressive competition in its sharing. In an era of Big Business and Big Labour such a basic contradiction can only lead to bitter fights that endanger the collaboration needed for production.

If the animosities developed when the wealth is shared weaken the whole economy and feed the inflation spiral when transferred to the stage of production, the obvious solution is to transfer the spirit of co-operation required by sustained production to the stage of the distribution of the shares.

It is certainly beyond the responsibility of the Committee to propose how this could be done. But it is not beyond reason to expect that management and labour in collaboration with governments could devise an effective system to preserve industrial peace while safeguarding their respective interests. Sweden and Switzerland have achieved this goal to the common satisfaction of business and labour and at the same time have produced two of the most innovative economies in the world. New developments in Canada and the United States that are basically variations of the Swedish and Swiss systems should also be seriously considered as a more general solution to our problem. The "Scanlon Plan" for labour-management co-operation may deserve particular attention. This plan is named after Joe Scanlon, a steelworker who developed and widely implemented a new and successful approach.[48]

There are some hopeful signs. In the past, when proper preventive and compensating measures have been taken, the Canadian labour movement has generally adopted a progressive attitude toward industrial conversion and technological change. Responsible labour leaders are becoming conscious of the fact that a growing number of Canadian companies are facing structural and long-term difficulties and that radical action is required to overcome them. So the Committee is not too worried that properly planned conversion and innovation programs will be opposed by the labour movement because of the temporary disruptions they might create. We expect that labour representation on the industrial task forces that would prepare the plans will ensure labour's active participation in this major national undertaking.

4. *The availability of private capital*

Capital is another important element. It will be needed to finance the radical structural changes required in building a more solid basis for innovation, and later it will be needed to fund the innovative process itself. The capital supply market in Canada will have a vital task to play. It has always been rather less dynamic and progressive than the market in the United States, probably because there has been less competition, a demand usually in aggregate exceeding the supply, and a prevailing attitude that security was preferable to higher but more risky returns.

The Science Council, noting that Canadians have a substantial investment of about $12 billion in American firms, has commented:

> Prudence is a commendable virtue, and the choice for the prudent Canadian investor is often between this country's developed resource industries, and other countries' developed manufacturing industries. . . .[49]

Canadian financial institutions must, of course, protect the interest of those who supply them with capital, but other things being more or less equal, they have a moral obligation to give preferential treatment to Canadian firms in their investment and lending policies because their funds originally come mainly from Canadian savings. Here again a change of attitude in our financial institutions is probably called for, which would certainly be accelerated if the Canada Development Corporation decides, as one of its major objectives, to support the conversion of secondary manufacturing industry in Canada. Like business management and the labour movement, the Canadian financial community must fully participate in this collective operation.

The financing of technological innovations is different from the financing of industrial conversion; it is a riskier business, requiring special know-how. Large companies wanting to innovate can usually meet their own financial requirements. The difficulties arise with small firms and especially with the launching of enterprises based on new technology. The OECD has noted:

> . . . the finance available for science-based entrepreneurs depends not only on the amount of capital available in a country, but also on the degree of confidence and comprehension existing between the scientific and banking communities, and on the degree of the latter's competence. The experience of the American Research and Development Corporation suggests that "venture capitalism" is a very special art. In the 21 years of its existence, it has reviewed several thousand proposals, and invested in 98 firms, the investment in general varying between $100,000 and $1,000,000. Approximately one out

> of five of these investments lost money, but the Corporation has retained an interest in 43 companies, the value of which is now about 16 times their original cost. In Europe, the creation of similarly specialised institutions has been more recent, but a number have been created over the past five years. Their experience so far suggests that there are ample opportunities for science-based entrepreneurship, that efforts must be made to create closer links between the scientific and banking communities, to train venture capitalists, and to channel more funds to science-based entrepreneurship.[50]

In Canada there are a few small firms such as the Canadian Enterprise Development Corporation that may be viewed as venture-capital undertakings. But their role in financing technological innovations appears to have had little impact. Is it because they have lacked initiative or because there have not been enough worth-while new ideas provided in Canada? One answer may be found in J. J. Brown's book, *Ideas in Exile* (*summarized in Appendix 2, Chapter 6, Volume 1*), which suggests that Canada has never been short of inventive talent and that many significant inventions were not developed in our country because of insufficient financial or industrial capability.

Members of the Committee have been approached by a number of Canadians with new ideas who did not know where to get help in transforming them into successful innovations. The Science Council has also noted:

> Risk-motivated venture capital companies do operate in Canada, but they are few and their resources are limited. In addition, they and their potential clients suffer from a communications gap: the venture capital companies are concerned—with just cause—about the management of possible new ventures; the Canadian entrepreneurs who approach them seem content with presenting a compelling case for the benefits to be realized, and tend to evade the management issue.[51]

As a consequence of that gap, good inventions are not transformed into successful innovations or they are applied in other countries. The Committee believes that it would be unrealistic to expect the individual inventor to have managerial skills and experience, so that the gap will never be filled unless venture capital companies are prepared to supply managerial advice and services. We hope, therefore, that in the future these companies will become better known in Canada, that they will be more aggressive in seeking good new ideas, and that they will extend their activities to the related management problems. On the basis of British and Swedish experience, it is unlikely that their financial resources and willingness to take risks will be sufficient to support all worthwhile ventures.

5. *The supply of qualified scientists and engineers*

A balanced supply of scientists and engineers is obviously a basic requirement of an innovative strategy. The problem that we face here is not an overall scarcity of QSEs. On the contrary, except in a few sectors there is a mounting surplus that could become critical if innovation and R&D in industry are not substantially increased. The difficulty lies in the mismatch in detail between supply and demand.

Canadian universities have faithfully followed the model proposed in 1919 that we described in Volume 1. They have insisted on training pure scientists; they have demanded basic science even in the training of engineers. Professor W. I. Schiff, dean of the faculty of science at York University, has described this "ivory tower syndrome" to the Committee and his statement deserves to be repeated here.

> We start inculcating in our students right from freshman year on in our science programs that pure science is the only pursuit; that it should not become polluted or contaminated; and in what we are teaching little relevance to society ever gets into our discussions. . . .
>
> We then point out to the students that the honours degree is certainly the only degree and that the ordinary degree is a consolation prize; and, furthermore, if they are any good, they must go on to get their Ph.D's. And then, at the Ph.D. level, the more esoteric the thesis subject the more value it is considered to have.
>
> What we are doing, then, is producing carbon copies of ourselves, because, after all, we have turned out so well the best thing we can do for the students is to make them over in our own image. [Graduates] find themselves faced with two difficulties . . . getting jobs, [and] an even worse one is the fact that frequently they do not want jobs outside. They want jobs in the university. So we have helped to create this monster ourselves.[52]

We could add that when graduates have not been able to remain in universities, they have sought work in government laboratories, mainly. They have been most reluctant to look for employment in industry, either for ideological reasons or because they have felt that R&D activities in that sector were of "an ephemeral value" and too prosaic.

The fact of the matter is that the history of successful industrial development in most countries shows that it is necessary for a large number of the most able scientists to have a strong motivation for linking their scientific expertise to industrial research. It is interesting to note that Dennis Gabor, the recent Nobelist in physics, has over 100 patents.

On the other hand Canadian industry has not been too interested in employing the graduates of Canadian universities. Industry representatives

repeatedly told the Committee that "we are educating our scientists and technologists for an unreal rather than a real world", that there is in "the universities . . . the attitude of an ivory tower where the application of research has been cut out", that a Ph.D. "very often becomes unhappy in industry because he finds shortly that he is moved to some project for which he perhaps was not trained at the university", that universities should give greater "attention to the supply of production-oriented engineers", that they turn out "well-trained people, but it is not the training we need to do the work we have", and that graduate scientists and engineers "lack a broad knowledge which would result from a well-rounded education".

Universities have put great emphasis on training pure scientists and science-oriented engineers and have been encouraged in this by the emphasis of government scholarships, fellowships, and research grants. Industry, meanwhile, has been interested in getting skilled engineers oriented toward the invention and innovation processes. As long as the academic sector and government laboratories were expanding, universities could neglect industrial needs without creating any immediate employment problem. Industry, on the other hand, has been meeting some—and in many cases the majority—of its requirements through immigration.

These two solitudes could not, however, continue forever. Now industry complains that "immigration has flooded the country with inadequately-trained foreign graduates who suffer also from lack of adaptability to Canadian methods".

The OECD, in its report on Canadian science policy, estimated the average net immigration of scientific manpower between 1954 and 1963 at 3,500 a year, but added a warning:

> The countries of Europe, however, have become conscious of the brain-drain menace and this awareness, together with measures adopted in these countries in favour of national research, will probably make it increasingly difficult to recruit scientific personnel in Europe. Canada will, therefore, have to rely more and more on her own universities to increase her scientific and engineering manpower.[53]

We have already indicated that industry must carry out more and better R&D. As it moves in that direction, its needs for Ph.D.s will increase, especially if their education is broadened; its reluctance to hire them will diminish; and it will be in a position to offer them more challenging jobs. At the same time the emerging surpluses will force a greater number of Ph.D.s to look to industry for employment. In the immediate future, extra inducements may be necessary on both sides to hasten the process. Industry could, for instance, offer

temporary jobs to students working toward a Ph.D. degree, which might influence the orientation of their studies and prepare them intellectually and psychologically for future permanent employment in the industrial sector.

It must be realized, however, that industrial demand for this type of specialized manpower has a definite limit, particularly for pure scientists. This means that the great emphasis universities have put on basic science should be reduced. It is now time to stop the spiraling of the "Ph.D. cycle" before it does a great disservice to students and the country at large. Universities must devote greater effort to the training of QSEs, at the B.Sc. and M.Sc. levels, who will be prepared to meet industry's need to develop its inventive and innovative capacity. They must also consider how the graduate education of scientists can be broadened to create the flexibility and talents required for industrial R&D.

The academic sector may be shocked at the suggestion that in future it must respond better to the needs of industry, but that would only prove how much of a revolution is needed in the mentality prevailing in universities.

It has been suggested that the ratio of engineering graduates to pure science graduates is an indication of a country's effectiveness in innovation.[54] In most countries the proportion of students taking first degrees in pure science *plus* first degrees in engineering has remained fairly constant but there are differences in the ratio of those taking their first degree in engineering to those taking a first degree in pure science. Figures for Japan, Germany, and Canada show that from 1956 to 1964 Japan produced about six engineers for every pure scientist, that the corresponding figure was about two for Germany, and that it declined from about two to less than one for Canada. Conditions in the first two countries were of course quite different from conditions in this country. The manufacturing industries of Germany and Japan, recovered from extensive war-time physical damage, were expanding rapidly, thus creating a more intense demand for engineers.

The university's role as the sole institution offering access to the highly skilled employment market should also be questioned. Perhaps we need other institutional forms for training the engineers, technologists, and designers required to fill "the problem-solving gap." The idea of a so-called Independent University, in practice a university independent of government financing and control and relying on business and industry for its funds, may be one kind of answer: the Independent University's apologists, at any rate, expect that it will be "more responsive to the demands of the private sector"[55].

All in all, the readjustment we are proposing cannot be carried out without the active participation of the academic sector but equally it cannot be

made successfully by universities alone. They need the collaboration of industry, which can best forecast its own requirements as a user of future QSEs. The conversion of universities in this area must become a joint venture.

The Committee recommends, therefore, that the Minister of State for Science and Technology appoint a task force composed of representatives of universities and industry to estimate the number and distribution of QSEs that the industrial sector will require in the 1970s and to determine the qualifications and training they should have, in the light of the government decisions regarding targets and strategies for industrial R&D and innovation during the decade.

We are aware of the difficulty of this assignment. Forecasting scientific and technological requirements in this age of rapid change is not an easy job, but preparing estimates on the best possible basis is better than having no general guidelines at all. It will be easier to determine the qualifications and training QSEs should have to meet industrial requirements. It seems that industries have fairly unanimous views on this matter, and these should be identified, appraised, and, if justified, implemented by universities and other teaching institutions. Fortunately while this problem of matching supply to demand is the more urgent, it is also the easier to define. Indeed, the main problem here, as presented to the Committee, is not quantitative but qualitative. If this effort of adaptation is begun soon, we feel confident that no bottleneck in the supply of scientific and technological manpower in Canada will develop.

In addition to the proposed study, we believe that more permanent steps should be taken to bridge the gap between the academic and industrial sectors. These two worlds must always be different because their missions are not the same. However, they are becoming more and more interdependent. Universities could not survive and expand without industry and, as the scientific and technological era develops, industry needs universities. The fact that in the past they have contrived to exist separately and cultivate a mutual contempt is no justification for maintaining the two solitudes in the future. What is required is an effort to build institutional links that will develop not only a continuing dialogue but concrete co-operation. But even here, patterns should not be imposed from the outside. This responsibility should be left to the two sectors. However, participatory democracy often needs an initial spark to begin to work, especially when it involves groups that have seldom had an opportunity to meet and start talking. We feel that Canadian universities and industry should be given this opportunity.

The Department of Industry, Trade and Commerce has taken an important initiative in setting up industrial research institutes and centres of excellence at some Canadian universities. But experience to date shows that success depends on the local environment and on the skill and dynamism of business management, university administration, and the management of the institutes themselves.

The Committee recommends, therefore, that the Minister of State for Science and Technology sponsor a national conference widely representative of the academic and industrial sectors to consider their complementary roles in the national science, technology, and innovation effort, to identify ways and means of helping each other to accomplish their missions better, and to devise the best possible permanent institutional basis for maintaining a continuing liaison and co-operation in the future.

6. *The management of industrial R&D and innovation*

Since R&D activities constitute an important source of technological innovations, the effective management of these operations is another element we wish to examine.

According to Patrick E. Haggerty, the president of Texas Instruments, when a firm decides to develop an innovative capacity, not only must this objective become a clear commitment of top management but it must be transformed into an institutional process:

> . . . we have made a serious attempt to institutionalise it by developing a system for the management of innovation. This consists of a formal statement of business objectives, a detailed summary of the strategies which will be followed to attain these objectives, and a series of technical programmes in such functions as research and development, manufacturing and marketing, with emphasis on the invention and innovation required. . . .[56]

Professor Quinn points out that successful strategic planning involves certain critical processes:

> 1. Development of stimulating—yet achievable—objectives which people understand and support.
>
> 2. Realistic assessment of the organization's own strengths and weaknesses relative to opposing forces.
>
> 3. Accurate evaluation of potential future opportunities and threats in the environment.

4. Thorough consideration of reasonable alternative programs to achieve major goals.

5. Conception of a unique posture based on the organization's comparative advantages and weaknesses.

6. Commitment of limited resources in a selective pattern which supports that posture.

7. Skillful execution of the strategy and tactical adaptation.[57]

Professor Quinn has illustrated these processes by referring to three cases involving a large, a medium-sized, and a small company.

The majority of industrial innovations according to Sumner Myers and Donald G. Marquis,[58] come from improvements in existing products or processes and the widening of market applications. Interestingly enough, E. Osmond has concluded that these operations do not create difficult management problems:

> With reasonable foresight and close collaboration between marketing and research, (such innovative activities) can be carried out effectively without really major decisions having to be made by the Board. . . .[59]

It is when the firm's R&D activities extend to the introduction of new products and processes or to "radical innovation," as they must if the company wants to maintain or improve its long-term market position, that management problems become more complicated. Marquis has commented on this area of innovative strategy:

> Research management is not only the critical difference between a good organisation and an average one, but research is the most difficult to manage of all functional activities. There are three sources of this special difficulty. The first is the degree of uncertainty. Compare, for example, the certainty with which you can plan and schedule production or inventory or sales or cash flow compared with what you can do in new product development. The second source of difficulty is that you are managing a new kind of employee who views himself as a professional person. Scientists and engineers differ from other employees in their expectations, their values, their attitudes and their motivations. The third source of difficulty is measuring results when each research task is unique and never repeated. Even if you could measure results, the delay in the feedback loop is so great that it is hard to use knowledge of results as a basis for planning in the future.[60]

The three levels of innovative activities just mentioned correspond to three types of strategies, sometimes described as absorptive, defensive, and offen-

sive. Individual firms should try to develop a mixture of the three strategies in order to maximize their short- and long-term opportunities and balance their risks. The most demanding, undoubtedly, is an offensive strategy, by which the innovator aims at being the first on the market with a new generation of products, as the OECD has suggested:

> . . . success will require strong R and D, considerable insights and creativity in science, technology, manufacturing engineering and marketing, and close coupling amongst them, together with access to a market environment receptive to technological innovation. It also entails the acceptance of big risks, but the possibilities of big pay-offs.[61]

Empirical studies show that while large firms can afford to have a staff large enough to embody all the skills needed for radical innovation—scientific, engineering, entrepreneurial, and managerial—the work tends to create tensions for them, conflicts between the business-as-usual attitude and the spirit of change, between innovators and administrative managers. These surveys also indicate that in big enterprises the ideal conditions for fruitful R&D—the coupling of R&D, production, and marketing; frequent contacts between R&D personnel and the rest of the staff; special encouragement to young QSEs; the proper balance between individual freedom and strong leadership in the carrying out of R&D programs and projects—seldom exist. To overcome these difficulties, T. Burns has suggested an "enterprise-centred" organization as opposed to a "management-centred" establishment:

> In management-centred organisations the problems and tasks facing the concern as a whole are broken down into specialisms. Each individual pursues his task as something distinct from the real tasks of the organization, as if it were the subject of a sub-contract. "Somebody at the top" is responsible for seeing to its relevance. The technical methods, duties, and powers attached to each functional role are precisely defined. Interaction within management tends to be vertical, i.e. between superior and subordinates. Operations and working behaviour are governed by instructions and decisions issued by superiors. This command hierarchy is maintained by the implicit assumption that all knowledge about the situation of the firm and its tasks is, or should be, available only to the head of the firm. Management, often visualised as the complex hierarchy familiar in organisation charts, operates a simple control system, with information flowing up through a succession of filters, and decisions and instructions flowing downwards through a succession of amplifiers.

> Entrepreneur-centred systems are adapted to unstable conditions, when problems and requirements for action arise which cannot be broken down and distributed among specialist roles within a closely defined hierarchy. Individuals have to perform their special tasks in the light of their knowledge of the tasks of the firm as a whole. Tasks lose much of their formal definition in terms of methods, duties, and powers, which have to be redefined continually by interaction with others participating in the task. Interaction runs laterally as much as vertically. Communication between people of different ranks tends to resemble lateral consultation rather than vertical command. *Omniscience can no longer* be imputed to the *head of the concern.*[62] [Emphasis added]

Because well-established large companies tend to be management-centred organizations, experience indicates that small, new, science-based firms are often in a better position to pursue an offensive strategy. They are not subject to internal tensions and conflicts and they do not have to protect existing lines of production. Thus they have greater freedom to manoeuvre. It is easier for them to realize the ideal conditions mentioned above for fruitful R&D and their innovative spirit is not paralyzed by an administrative bureaucracy. On the other hand, this sort of small firm is usually weak at the managerial stage, defined by J. Bright as the stage of optimization of usage of the innovation.[63] Several factors may account for this weakness: the absence of a sound administrative basis, for instance, or the lack of capital and marketing facilities.

R. Seiler has questioned research managers about the accuracy with which R&D projects can be appraised. He summarized their answers in a table, which is reproduced below.

This table suggests that when it comes to estimating the cost and time to complete projects, greater accuracy is possible with development projects than research projects. The study suggests that estimating benefits is easier with new processes than new products. Commercial success can be predicted more precisely than technical success. The main weakness appears to be market evaluation. This area is more the province of the social sciences and particularly of specialists in marketing. It involves great difficulties and that explains part of the failures but very likely it has also been neglected by R&D management. It would be worthwhile hiring more qualified people and improving techniques so as to reinforce this important factor in project appraisal. A recent report of the European Industrial Research Management

Association sums up the present state of the art in this whole area of project selection:

> . . . there is a fairly general feeling of dissatisfaction with the existing procedures for project selection. Virtually all research managers are highly interested in formal methods for this purpose although in fact freely admitting that they do not make much use of them. Furthermore, as projects become more complex, as the rate of technological advance increases, it is becoming increasingly difficult to make satisfactory intuitive decisions. More and more, the need is being felt for rendering explicit the implicit assumptions and hypotheses upon which intuitive decisions are based. However unsatisfactory the existing formal methods may be, the use of no method at all is likely to be even worse. It is felt, therefore, that it is very much worthwhile to devote effort to improving techniques and, perhaps even more importantly, to acquire experience in the application of such techniques; without this experience the essential feedback which will assist further development will be lost.[64]

Table 21—Research Management's Opinion of the Accuracy with which Factors Affecting Research Projects can be Estimated, 1964

Factor	Accuracy Rating					
	Excellent	Good	Fair	Poor	Totally Unreliable	Total
	Percentages					
Cost of the research project	3.5	27.8	52.2	14.8	1.7	100
Cost of development if the research is successful	2.6	38.8	46.6	9.5	2.5	100
Probability of technical success	3.5	51.3	39.9	6.3	0.0	100
Time necessary to complete the research	0.9	18.6	50.4	24.8	5.3	100
Manpower requirements necessary to complete the research	2.6	34.2	53.5	7.0	2.7	100
Probability of market success	3.6	33.6	38.2	14.5	10.1	100
Time necessary to complete the development	1.8	34.5	41.8	17.3	4.6	100
Market life of the product if R and D efforts are successful	4.6	28.0	29.0	23.4	15.0	100
Revenue from the sale of the product if R and D are successful	5.3	36.0	28.9	27.2	2.6	100
Cost reductions if R and D efforts are successful	10.7	57.1	14.3	14.3	3.6	100

SOURCE: Seiler, R., *Improving the Effectiveness of Research and Development*, McGraw-Hill Book Company, New York, 1965 (reproduced in OECD, *The Conditions..., op. cit.*, p. 69).

Co-operative arrangements are another problem. Two different approaches have been followed. The first involves pooling part of the R&D activities carried out by an industry and creating a central institute to service the entire

industry. The Pulp and Paper Research Institute of Canada is an example. In the second, several firms belonging to different industries pool complementary activities and facilities. The Sheridan Park Association located near Toronto is attempting to develop on this pattern.

In theory these two ways of pooling R&D activities and facilities offer distinct and different advantages. (They are not, incidentally, mutually exclusive, although we know of no example of a central research institute located in a research community.)

The centralization of an industry's R&D should normally lead to the accumulation of a critical mass of QSEs, a reduction in costs, and improved performance. To be successful, however, the innovative process must become more secret and be adapted more closely to the objectives of an individual firm the nearer it gets to the goal. Obviously not all R&D activities can be centralized, and individual firms, when they are of sufficient size to afford it, must retain their own R&D operations.

It is interesting to note that the horizontal pooling of R&D operations, which has been tried most extensively in Great Britain, has not so far been generally successful and that in Canada it has been limited to the pulp and paper industry, which was probably influenced by government grants. The Committee believes, however, that this type of pooling can play a useful role in Canada provided its mission is clearly defined and the top management of individual companies keeps an active interest in it so that they are in a position to prevent their own R&D units duplicating its activities uselessly. In general one can say that these central organizations could be a better alternative to government laboratories operating in the same field, because they are closer to industry.

The pooling of complementary R&D activities by firms from different industries presents quite different features. These associations do not give rise to the rivalries and conflicts that horizontal pooling may develop and they provide a better environment for the free exchange of views and person-to-person contacts. However, the R&D facilities of the firms involved would then usually be remote from their production facilities and their top management, which is not helpful for the continuity of innovative strategy. Moreover, the diversity of industries and their different requirements may seriously limit the pooling of activities and facilities.

The main problem faced by these associations appears to be how to select industries to maximize the benefits of proximity. Their primary objective, it seems, should be to choose firms belonging to industries that are related

vertically or that require R&D programs in related disciplines. The impression the Committee got from the experience of the Sheridan Park Association was that the original selection of firms was not clearly inspired by the objective of maximizing complementarity and that, as a result, not all the benefits to be derived from this kind of pooling had yet been achieved. However, we feel that this formula, like horizontal pooling, offers distinct advantages for a medium-sized country like Canada, provided the right strategy is used to develop its full potential. The establishment of contract R&D organizations such as A. D. Little and Battelle should also be considered. These firms can supplement or complement a company's R&D group or even at times substitute for it.

It seems obvious that effective management is a key factor in developing innovative capacity and that there is still a lot of progress to be made here. Professor E. Roberts, of the Sloan School of Management at MIT, has summarized the American situation:

> Because R and D is a very young corporate activity, the practices of R and D management are still in the infancy stage of development. . . . R and D suffers from a lack of standards of performance, a lack of a true understanding of its process, and a lack of an organised educational basis for its managers. This accounts for the fads, the "magic" techniques, the unfounded philosophies. Indeed, I believe R and D has more of the mystique about it than any other area of management.[65]

If this is the situation in the United States where most of the research on this problem has been conducted, it is not unreasonable to conclude that Canadian conditions are even worse, because as far as the Committee knows, very little has been done here to study the practices and results of innovative strategies and certainly not enough attention has been devoted to the training of R&D managers.[66] A special effort should be made to fill or at least reduce these two gaps. In this respect, the means and scope of the Canadian Research Management Association have been rather limited compared with the needs.

The Committee feels that the responsibility for the training of R&D managers clearly belongs to schools of management. They should become the main centres of research on the complex problems of R&D management and innovation strategies since it is essential to build a direct coupling between research and training in this area. However, they should not fulfil these two responsibilities in isolation. They should get the advice of the Canadian Research Management Association and the collaboration and support of the Canadian government.

The Committee recommends, therefore:

1. That the Minister of State for Science and Technology set up a special committee with representatives from Canadian university schools of management and the Canadian Research Management Association to develop a training program for R&D managers and a research program on the organization of R&D activities and of innovation strategies;

2. That the committee select Canadian centres in different regions to be mainly responsible for the proposed training program and choose the best qualified researchers to carry out the research program; and

3. That the Minister of State for Science and Technology establish a program of scholarships to be awarded by this management training committee and provide the full financing of the research program and an annual grant to the Canadian Research Management Association to enable it to extend its activities in conjunction with the proposed programs.

The Committee feels that in view of the limited demand for R&D managers at the moment in Canada, at least two institutions specializing in this kind of training would be sufficient initially, provided they extend their services to the main regions of Canada. But the research program should be more decentralized, to allow the participation of qualified researchers not located in the selected institutions. We also believe that the active collaboration of R&D managers in industry and government is essential to guarantee the realistic implementation of the two proposed programs. The Canadian association, through its diverse composition, is well qualified to represent them and to provide the collaboration required; it needs to be strengthened, however, and to receive additional financial support.

CONCLUSION

The Committee has found that the present private climate surrounding industrial R&D and innovation in Canada is not good. Its internal weaknesses are not insuperable but they are major. Canadian private institutions in general have not been innovation-oriented. Our industries have maintained a passive attitude that tariff protection, the abundance of natural resources, and easy access to foreign capital and know-how helped to develop. Our financial institutions have a reluctance to take risks in a country where venture capital has always been scarce. The labour movement has become more

anxious to consolidate its position than to accept change that would improve productivity and sustain growth. Our universities have tried to preserve their traditional role as sanctuaries of pure science and basic research. Industrial R&D managers, too remote from top management, have been tempted to cultivate the mystique of research, which has left them too often without standards of performance or a true understanding of the complexity of the innovation process.

The Committee's recommendations and suggestions will not only require a structural revolution in many private institutions but also a conversion of their leaders to a new mentality and new attitudes. Canadian society must become collectively more creative and innovative. This large scale operation must be undertaken primarily by the private sector. This is the only practical avenue that Canada can take to improve its innovative performance and join the international technological race before the decade is too far advanced.

NOTES AND REFERENCES

1. Garrett Hardin, "The Tragedy of the Commons", *Science,* 13 December 1968, p. 1244.
2. Richard E. Caves and Grant L. Reuber, *Canadian Economic Policy and the Impact of International Capital Flows,* University of Toronto Press, 1969, p. 34.
3. John McHale, "World Facts and Trends", *Futures,* Vol. 3. No. 3, Sept. 1971, pp. 216-301.
4. Meadows, Donella H. and Meadows, Dennis L., *The Limits to Growth,* Universe Books, New York (in press).
5. Quoted by Irving Whynt, "Sure bet for the future: cost of oil will continue to rise", *The Ottawa Journal,* October 25, 1971, p. 8.
6. Quoted in "Dearth of minerals is foreseen in U.S.", *The Globe and Mail,* August 3, 1971.
7. John McHale, *op. cit.*
8. M. King Hubbert, "Energy Resources", Chapter 8 of *Resources and Man,* A Study and Recommendations by the Committee on Resources and Man, U.S. National Academy of Sciences—National Research Council, W. H. Freeman and Company, San Francisco, 1969, pp. 238-239.
9. *Innovation in a Cold Climate,* Science Council of Canada. Report No. 15, October 1971.
10. J. L. Orr, "A Technological Strategy for Industrial Development", *Industrial Canada,* January, 1969.
11. Dorothy Walters, *Canadian Income Levels and Growth; An International Perspective,* Economic Council of Canada. Staff Study No. 23, Queen's Printer, 1968.
12. Sir Alec Cairncross, "Government and Innovation", *New Scientist and Science Journal,* 2 September, 1971, p. 502.
13. Economic Council of Canada, *Fifth Annual Review,* Queen's Printer, Ottawa, 1968, p. 41.
14. Science Council of Canada, *Towards a National Science Policy for Canada,* Queen's Printer, October, 1968, p. 1.
15. *Fifth Annual Review,* op. cit., p. 56.
16. *Innovation Newsletter,* No. 23, Special Issue, Report on Conference Workshop 3, published by Technology Communications Inc., New York, 1971, p. 6.
17. Ibid.
18. James Brian Quinn, "Scientific and Technical Strategy at the National and Major Enterprise Level", paper prepared for UNESCO Office of Economic Analysis, Symposium on The Role of Science and Technology in Economic Development, December 11-18, 1968, p. 11, (available from Professor Quinn at Amos Tuck School, Dartmouth College).

19. William N. Leonard, "Research and Development in Industrial Growth", *Journal of Political Economy*, March-April, 1971, p. 232.
20. Ibid., p. 233. (Here Leonard refers to studies by Griliches 1958; Mansfield 1965b; Sherer 1965; Fellner 1970.)
21. Ibid., p. 254.
22. James Brian Quinn, *op. cit.*, p. 57.
23. Donald A. Chisholm, "Thoughts on Innovation in Canada", address to the Annual Meeting of the Association of Professional Engineers of the Province of Ontario, Hamilton Area Chapter, May 6, 1971, p. 6.
24. *Summary White Paper of Science and Technology—Promoting Development of Japanese Technology*, Science and Technology Agency of Japan, March 1969, pp. 3-4.
25. Harold Crookell, "The Marketing Implications of Free Trade between Canada and the U.S.", *The Business Quarterly*, University of Western Ontario, London, Ont., Autumn, 1968.
26. Peter Meyboom, "Technological Innovation in Canada", Working Paper No. 7100, Department of Finance, Ottawa, 1970, (mimeo).
27. *"Research and Development in U.S. Industry—1969"*, National Science Foundation, Washington, D.C.
28. OECD, *The Conditions for Success in Technological Innovation*, Paris, 1970, pp. 48 and 49.
29. P. M. S. Blackett, "Memorandum to the Select Committee on Science and Technology", *Second Report from the Select Committee on Science and Technology, Session* 1968-69; *Defence Research*, Her Majesty's Stationery Office, London 1969, p. 90.
30. Peter Meyboom, *op. cit.*
31. Steven Globerman, "The Empirical Relationship Between R & D and Industrial Growth in Canada", an unpublished paper prepared at York University, Toronto, p. 15.
32. Ibid., pp. 5-6.
33. *The Conditions for Success . . .*, op. cit., p. 49.
34. Samuel Lilley, "Technological Progress and the Industrial Revolution", Chapter 3 of *The Fontana Economic History of Europe*, Volume 3, London, 1970, pp. 39-40.
35. Senate Special Committee on Science Policy, *Proceedings*, No. 68, June 19, 1969, p. 8122.
36. Ibid., p. 8130.
37. Ibid., p. 8130.
38. *Innovation in a Cold Climate, op. cit.*, p. 31.
39. OECD, *The Conditions for Success . . . , op. cit.*, pp. 53 and 55.
40. Although Tables 18 and 19 were compiled from separate surveys, it is highly probable that they essentially deal with the same firms and that the firms with low sales are the firms with few QSEs.
41. OECD, *The Conditions for Success . . ., op. cit.*, pp. 72 and 73.
42. Senate Special Committee on Science Policy. *Proceedings*, No. 65, June 17, 1969, p. 7898.
43. Ibid., p. 7895.
44. Ibid., No. 67, June 18, 1969, p. 8089.
45. *Innovation in a Cold Climate, op. cit.*, p. 33.
46. Ibid., p. 32.
47. Chris Argyris, "Organizational Illnesses: Possible Cures", lecture delivered at University of Toronto, October 15 and 16, 1968, sponsored by the Canadian Imperial Bank of Commerce and reprinted in *Commercial Letter*, October 1968.
48. The Scanlon Plan, *A Frontier in Labor-Management Cooperation*, ed. by F. G. Lesieur, The M.I.T. Press, Cambridge,1958.
49. *Innovation in a Cold Climate, op. cit.*, p. 30.
50. OECD, *The Conditions for Success . . ., op. cit.*, pp. 45-46; see also R. Winsbury, "Financing the Entrepreneur", in *Management Today*, October 1968 and W. Congleton, "Invention and Innovation: The American Experience", in *Technology and Society*, May 1969.
51. *Innovation in a Cold Climate, op. cit.*, p. 30.
52. Senate Special Committee on Science Policy, *Proceedings*, No. 47, May 28, 1969, p. 5929.
53. OECD, *Reviews of National Science Policy, Canada*, Paris 1969, p. 236.
54. E. Rudd, "Rate of Economic Growth, Technology and the Ph. D.", *Minerva*, Spring 1968.

55. Gillian Peele, "The independent university faces the future", *The Financial Times*, November 13, 1971. See also *University Independence: The Main Questions*, ed. John MacCallum Scott, Rex Collings, London, 1971.
56. P. Haggerty, "Innovation and the Private Enterprise System in the United States", address before the National Academy of Engineering, 24th April, 1968 (quoted by OECD in *The Conditions for Success . . .*, op. cit., p. 62).
57 James Brian Quinn, *op. cit.*, p. 22.
58. S. Myers and D. Marquis, *Successful Technological Innovations*, National Science Foundation, NSF 69-71, Washington, 1969.
59. E. Osmond, "Making the Most of One's Own Resources—Research and Development", paper read at a National Conference on Technological Innovation. University of Bradford Management Centre, 12th and 13th March 1969 (quoted by OECD, *The Conditions . . .*, *op. cit.*, p. 58).
60. D. Marquis, "The Knowledge Base for Education of Research Managers", paper presented at the 19th National Conference on the Administration of Research, published by the Denver Research Institute, April 1966 (quoted by OECD, in *The Conditions . . .*, *op. cit.*, p. 57).
61. OECD, *The Conditions . . .*, *op. cit.*, p. 74.
62. T. Burns, "The Innovative Process and the Organization of Industrial Science", in *Main Speeches, Conference Papers*, Volume V, European Industrial Research Management Association, Paris 1967 (quoted in OECD, *The Conditions . . .*, *op. cit.*, p. 61).
63. James R. Bright.
64. *Project Selection and Review*, Report No. 1 of Working Group No. 6, Paris 1969 (quoted by OECD in *The Conditions for Success . . .*, *op. cit.*, p. 71).
65. E. Roberts, "The Myths of Research Management", in *Science and Technology*, August 1968 (quoted by OECD in *The Conditions . . .*, *op. cit.*, p. 57).
66. Dr. Donald A. Chisholm, President of Bell-Northern Research, is one of the few in Canada who has publicly expressed his interest in this field. Recently he has noted that R&D "in the simplest terms" is to be regarded "as the organizational process which catalyses innovations" but he goes on to analyse the changes which will be required in the firm's overall R&D system. See "Change and be Changed; The Road Ahead for R&D", *Telesis* 2/1, Spring 1971, pp. 2-7.

16

INDUSTRIAL INNOVATION AND THE CANADIAN GOVERNMENT'S IMPACT

The Canadian innovation operation just described cannot be successfully carried out by the private sector alone, even if it actively participates in making the operation a collective and united effort. Governments have been playing an increasing part in our mixed economy and their influence on the rate and direction of industrial growth can be very great. We are used to regarding governments as complementary and compensatory, but their role can become the determining one in the most volatile areas of private industrial activities, such as technological innovation.

Through policies aimed at serving other national and regional goals, governments can unconsciously create a public environment that is favourable or unfavourable to the private innovative process. It can also take measures specifically designed to affect innovation. Sir Alec Cairncross stated recently:

> Concentration on R & D is less helpful to innovation than concentration on industrial efficiency, for true industrial efficiency must embrace the ability to innovate successfully. This still leaves an important role for government. There are many ways in which it can contribute to industrial efficiency, even from outside, and so encourage the more rapid diffusion of new technology towards which its strategy should be directed first and foremost. It alone can adapt the education system to the needs of an industrial society undergoing rapid and continuous technological change. It can try to maintain competitive pressure and get rid of restrictive practices, particularly those that stand in the way of innovation. It can take action to reduce uncertainty, stimulate investment and improve the level of management.[1]

Holloman and Harger made about the same comments in a recent article designed to convince the American government to take a broader view in its policies for supporting the industrial innovation process:

> In some way, also, government must underwrite industrial research and development itself, since the economy has always tended to under-invest in it. . . . This can be done either directly by subsidy or indirectly through tax rebates. The entire set of corporate and government policies that encourage potentially high-export industries needs to be reviewed. . . . The effective use of technology requires that a large number of appropriate conditions be met simultaneously; a single missing ingredient (for example, the absence of available capital, or the necessary management attitudes) may completely halt either technological innovation or the spread of technology within the society.[2]

This chapter is limited to an examination of the Canadian government's general impact on the industrial innovation process. The Committee is aware of the important role that the provinces can play. But we do not feel that our responsibility extends to the provincial area although we make a few general references to it. We begin by showing the need for a new, coherent, and positive industrial strategy and indicating what its broad objectives should be if the actions of government are to achieve their most beneficial effects. As we stressed in Volume 1 we consider that "first generation" science policy must include industrial strategy.

A NEW NATIONAL POLICY

Since Confederation in 1867, Canadian governments have adopted two quite different strategies to foster economic development. During the first decades of the 20th century one was superimposed on the other. The first, developed by Sir John A. Macdonald, rested mainly on construction of the first transcontinental railway and high tariff protection. Although there was practically no alternative at the time, in the long run protectionism attracted branch plants that merely reproduced for the smaller Canadian market products developed by their foreign parent companies.

The second strategy, initiated by the Laurier government, was centred on the opening of the West, which gave a great impetus to the expansion of secondary manufacturing in Central Canada. When Sir Wilfrid Laurier tried to negotiate free trade with the United States, he was defeated in 1911. In the meantime, the second major technological revolution was beginning in the United States. With continued tariff protection, it brought a new kind of American subsidiary to Canada, secondary manufacturers of products of the new revolution, such as motor cars and electrical appliances.

But the new revolution required new resources, such as pulp wood and new minerals, as well as cheap hydro-electric power. The Americans soon

realized that they did not have such resources, at least not in sufficient quantities, but that Canada had. This precipitated an American economic invasion in the sector of natural resources, which came under provincial jurisdiction. Thus, as a result of new technologies, Canadian industrial strategy was almost automatically transferred from the federal government to the provinces. After the long period of slower economic growth in the latter part of the 19th century, the provinces were only too happy to welcome American capital and its new subsidiaries in the resource-based sector. Tariff and export trade policies were practically the only important areas of industrial strategy left to the central government and they were used to reinforce provincial objectives. Canada became a leading supporter of more liberal trading arrangements in the hope of gaining easier access to foreign markets for its primary products.

This somewhat passive strategy brought rapid economic growth. American needs, capital, and know-how were the prime determinants of Canadian growth. In 1900, United States investment in Canada was only $205 million or 15.7 per cent of total foreign investment. By 1967 it had reached $28 billion or 81 per cent of long-term foreign investment in Canada.

Now a new era of world economic conditions is emerging and it will likely last at least until the end of this century. By the year 2000, if we assume a "surprise-free" scenario, world population will double, new trade patterns will develop, multi-national corporations will come to dominate the international economic scene, resources will be rapidly depleted, and the international technological race will gain momentum. Because of this new world context, the Committee has concluded that Canada needs a new National Policy—a new national industrial strategy—and that the Canadian government should use all the weapons at its disposal to implement it, with the active participation and collaboration of the provinces.

Some Canadians disagree with that conclusion. They argue that many segments of our secondary manufacturing industry, even where subsidiaries dominate, will not be able to meet foreign competition and that we should continue to rely on the export of the primary products of our resource-based industries, together with the contribution of service industries, to fill the gap. This subtle continentalism might seem the most normal approach since it appears to rest on the principle of comparative advantage and on the natural complementary relationships that have developed between the United States and Canada. It might be the right thing to do if world reserves were abundant and growing. But it is becoming more and more evident that the opposite is true, so that continuation of the old passive strategy, while tempting in the short run, would be unwise in the long term.

It is our impression that a growing number of Canadians want a new industrial strategy, though they disagree on its content and direction. Two opposite and extreme views are developing.

The first extreme view is that Canadian subsidiaries, especially in the resource field, should be taken over by the Canadian government. These socialized firms would then be free to further process their primary products in Canada and to deal in world markets on their own terms. This solution would certainly precipitate a serious constitutional crisis in Canada. The money needed to compensate foreign parent companies would be staggering. It would involve a degree of socialism that most Canadians would find unacceptable. And even then foreign markets might not prove easily accessible to the new socialized firms; there will still be alternative sources of supply for most primary products, at least in the 1970s.

The opposite extreme view favours free trade with the United States. Even if this forthright continentalist approach were acceptable to both parties, which is very doubtful, it would strike a fatal blow at many already weak secondary manufacturing industries, and it would not necessarily change the existing vertical relationship between U.S. parent companies and their Canadian subsidiaries in the resource sector. Even if it became more profitable in the long run for U.S. companies to further process primary products in Canada, this would mean a reduction of manufacturing operations by the parent firms that they might well find unacceptable. A final consideration is that it has been found in Europe that free trade arrangements lead naturally to the integration of most other areas of economic policy. Between countries as different in size as the United States and Canada, such an integration would inevitably mean that Canadian economic policies would be completely determined by Washington and, under such conditions, Canada would not remain a separate and distinct political entity for long. And a policy of this kind, once embarked on, is almost irreversible.

The advocates of this approach often refer to the development of the Canadian newsprint industry to support their views. They point out that it expanded rapidly after free trade was established in 1913. They forget, however, that a major cause of the expansion was the imposition of provincial embargoes on the export of pulpwood; they forget that further processing by Canadian subsidiaries did not in this case come into conflict with the activities of their parent companies, mainly American newspaper companies, but on the contrary was definitely to their advantage because it provided them with ample long-term supplies at lower prices. Obviously this particular model would not apply to most industrial sectors.

The Committee feels that the debates on the orientation and content of a new industrial strategy for Canada has been too heavily dominated by the emotional issue of foreign ownership, leading the protagonists to extreme and unrepresentative views. There are a growing number of Canadians who are worried by the extent of U.S. industrial ownership and control but who realize that the risk will be with us as long as we want to derive the benefits of close economic relations with the United States. What they are really asking is that Canadians and their governments abandon the passive old industrial strategy that created this situation. But reducing U.S. control over the Canadian economy and more closely supervising the performance of Canadian subsidiaries can only be part of a positive new strategy. Its primary goal should be to maximize the flow of innovations from Canadian industry. In other words, the new National Policy should rest mainly on an imaginative and creative technological strategy using the full potential of a better educated labour force and designed as a major source of future Canadian economic growth.

This national goal has three main implications for government policy:

1. The Canadian government and the provinces should support the structural conversion of the secondary manufacturing sector so as to enable it to deal speedily and effectively with the problems of rationalization and scale and establish a strong basis for innovative capacity.
2. Once that basis has been established, government policies should be designed to encourage the secondary manufacturing sector to use its stronger innovating capacity to penetrate international markets. Other larger or smaller countries have succeeded in doing this: Finland, for instance, has built over 50 per cent of the world's icebreakers since World War II. Canada should be able to follow their example.
3. Although most resource-based industries consist of firms large and specialized enough to have a strong innovative capacity, they do not use it extensively. Government policies should be designed to encourage these firms to do more—to help slow the rapid depletion of Canadian reserves and combat pollution, to reduce their costs and find new uses for their production, to extend their processing operations in Canada at a cost that would enable them to penetrate world markets with their finished products. Government policies should be turned mainly on this last objective. We have deplored our national

role as "hewers of wood and drawers of water" but little has been done to change it, except when the provinces imposed embargoes on export of pulpwood at the beginning of the century.

Canadians tend to underestimate the advantage for a parent corporation of having ready access to raw materials in countries with stable political systems. Combined with a growing shortage of many important natural resources, this will give Canada greater bargaining leverage for insisting on further processing. Many countries are already successfully applying this strategy. Ontario, Manitoba, and British Columbia now require increased processing of some metal ores.

The Committee believes, therefore, that the new industrial and technological strategy to be implemented by the Canadian government should create larger industrial units, encourage them to innovate, and build on our raw material base more effectively by requiring further processing in Canada. If these objectives could be achieved, through private initiative and government support, a solid basis would be established for sustained and more balanced growth in Canada.

THE ENVIRONMENT FOR PUBLIC ACTION

Canadian industry has been arguing that various government policies operate to the detriment of profitability and growth, and therefore of industrial innovations and R&D activities in this country. The assertion was made repeatedly before the Committee during its hearings (*see Proceedings for detail, Chapter 9, Volume 1 for highlights*). In a memorandum addressed to the Chairman of the Committee, dated May 1971, the Canadian Chamber of Commerce stated:

> The first key requirement for improved research and development is for the government to establish, as quickly as possible, a climate in Canada for economic development.
>
> The second key requirement is for improved access by the high-value Canadian industries to major markets abroad. This would provide a base for improved domestic competitiveness due to larger scale operations, and a base for renewed growth at home and abroad. The key markets are those of the U.S., the E.E.C., Japan and EFTA. Canada is the only major industrial nation without direct participation in a market of 100 million people or more. . . . If satisfactory access to the key foreign markets cannot be obtained, the Chamber feels that the nation will face very severe problems of industrial survival.

In order to benefit from these improved market access arrangements the Chamber believes that there will be urgent need for a *national strategy for industry* which would identify, and give special encouragement to, the preferred high-value secondary industries for Canada. A clear industrial strategy, with support priorities, would be essential for success under the challenges and opportunities of real access to the key markets. . . .

In the meantime it must be recognized that the present decline in industrial research and development is highly detrimental to the nation. For one thing, it is adding greatly to the problems of employment today for "highly qualified manpower". However, more importantly, industry is failing to acquire a greater pool of scientific resources (both manpower and facilities) not only for research and development but for the increasingly complex technology of its production. It is, therefore, essential that the current trend be arrested and preferably reversed, in the immediate future.

Dr. H. F. Hoerig, vice-president (research and development) of DuPont of Canada Limited, raised more specific issues affecting the chemical industry in a letter to the Chairman in March 1971:

The economic environment, reflecting Government policies, can be defined as follows:

1. World leadership in reduction of chemical and chemical end-product tariffs without equitable tariff levels among other producing countries. Acceptance of a role as an attractive area for large foreign imports from countries whose manufacturers enjoy relatively closed markets.
2. High rates of taxation and anti-combines legislation which hinders an effective response to the small-scale problem.
3. High taxes on building and construction materials which in combination with high construction labour rates and the scale factor results in investment cost per unit of capacity being the highest in the world.
4. The Canadian dollar remaining at par or at a premium over the U.S. dollar, placing the industry at a further disadvantage.

The conditions outlined above have and will continue to exert a profound adverse influence on the scale of Canadian industrial chemical research and development. It is axiomatic that industry adapts its operations to the environment in which it is required to operate. Under the terms of present national policy, it is clear that the industry will move toward simplification of its product lines, retaining for production in Canada only the larger-volume products least vulnerable to foreign competition across an open border. With reduced scope and no opportunity for significant diversification there can be no option but to adjust the R&D effort to a level consistent with diminished long-term opportunity. This process appears to be well under way and is a most regrettable but necessary response to the realities emerging from Government policy. No system of cash incentives or grants is likely to reverse this trend in the absence of a sound, long-term, profitable investment climate.

While noting that the tariff policies referred to by Dr. Hoerig are in fact producing a form of rationalization in the chemical industry, there is no doubt that this is being achieved at the expense of substantial dislocation. The higher tariffs into the U.S. market do not give Canadian suppliers, even if they were to build plants of equal scale, the same opportunity in U.S. markets that U.S. suppliers have in Canada.

These comments make it clear that there are many aspects of government policy that fall outside the immediate scope of science policy and yet exert a powerful influence on the innovative performance of Canadian industry. Some of the more important elements of federal government policy that impinge on the innovation process in the private sector are tabulated below:

Policy	Government Agency	Implications for Innovation
Trade	Industry Trade and Commerce	Access to international markets and promotion of sales of Canadian goods.
Tariff	Finance	Reciprocal tariff concessions and protection of domestic manufacturers.
Fiscal	Finance	Direct and indirect taxes related to industrial development, investors, and entrepreneurs.
Monetary	Finance	Supply of money; interest rates, affecting investment capital; exchange rate, influencing exports and imports.
Foreign Ownership	Finance	Foreign subsidiaries and Canadian innovative ability and performance.
Procurement	Supply and Services	Government purchasing power influencing product development and new technology.
Competition	Consumer and Corporate Affairs	Regulation of monopoly practices, conversion of secondary manufacturing sector.
Standards	Industry Trade and Commerce	Industrial standards relating to quality and performance of manufactured products.
Industrial Relations and Manpower	Labour and Manpower and Immigration	Labour Code provisions and retraining of skilled labour in connection with technological change.
Patents	Consumer and Corporate Affairs	Patent protection affecting invention exploitation in Canada.
Regional Development	Regional Economic Expansion	Regional location of industry; industrial fragmentation.
Pollution Control	Environment	Control of industrial pollution and the use of technology.

It is obvious that decisions taken in most of these sectors are inspired by national goals other than the encouragement of industrial innovations and R&D. This is as it should be. But at present they are usually taken without proper regard for their potential impact on the innovation process. As a result they can create serious impediments, for which the most generous direct incentive programs for industrial innovations and R&D activities cannot compensate. This is one important area where government policies can contradict each other and thus substantially reduce their net beneficial effects.

The point we wish to make here is not that the policies mentioned should be diverted from their main goals, but that when they are being formulated, a conscious and systematic attempt should be made to measure the kind of impact they are likely to have in the light of the new industrial and technological strategy proposed by the Committee. At worst, the examination would show the government the consequences its general policies would be likely to have for the innovation process. At best, it could lead to changes that would encourage industrial innovations.

These policy areas are so numerous and broad that our examination cannot be exhaustive. We want to bring out some specific points, but our main purpose is to convince the government to set up a special inter-departmental mechanism for studying the impact of all these policy areas on the flow of industrial innovations so that the departments concerned can see the implications of their policies and the Cabinet can be given any necessary recommendations.

1. *Trade and tariff policy*

As the Canadian Chamber of Commerce suggested in the memorandum quoted above, Canada is one of the very few advanced industrialized nations without free access to a market of 100 million or more consumers for its finished products. The European Economic Community, already the largest free-trade grouping of countries, is not only planning to take in the United Kingdom, Denmark, Norway, and Ireland, but is discussing plans for the free trade of industrial products—except for certain sensitive goods—with Sweden, Switzerland, Austria, Finland, Portugal and Iceland as well, which will add up to a free market more on the order of 300 million.

Trade barriers do not necessarily prevent the products of a highly innovative economy from penetrating foreign markets. They do represent a serious impediment, though; and as the technology the product is based on is diffused around the world, the number of competitors increases and profit

margins are likely to drop. Much of Canadian industry is based on technology that is mature, and is likely to continue to be based on technology that is mature. A North Atlantic free trade area might offer us substantial benefits, but not in this decade. Several members of the European Economic Community would refuse Canada full participation, though a special arrangement on industrial products along the lines of the arrangements being discussed with Sweden and the other countries could be explored.

For the moment, at least, our country's isolation should be a cause for concern but not panic. We should keep our options open and not immediately seek a fundamental re-alignment that we might regret in the 1980s. The emerging trade policies of other nations are contradictory, confusing—and almost certainly temporary. A trade war leading to higher protectionism is unlikely. Enlarged by Britain, Denmark, Norway, and Ireland, the EEC will account for more than a third of world trade. It will need the American market to sustain its prosperity—even more if it extends to include the special participation of countries like Sweden, Switzerland, and Finland. Japan is certainly not in a position to isolate itself from world markets. While the United States does only about 15 per cent of world trade, it wants to expand its exports, a goal not to be achieved by continually increasing its tariffs. For all these reasons we expect more liberal trade policies worldwide in the long run rather than the reverse.

The present confusion should soon lead to another major round of trade negotiations. It is time Canada re-examined its position. Instead of preoccupying itself with obtaining the most favourable entry into foreign markets for raw materials and primary products, the objective should be to reduce obstacles to the sale of Canadian manufactured products in traditional markets and to develop new markets elsewhere. This goal could be more easily achieved if it were supported by the reduction of the substantial tariff and non-tariff barriers that still restrict access to foreign markets for Canadian manufactured products. The Committee proposes that the principle of equal rates of tariff on manufactured goods should become the cardinal point of our future trade negotiations, so that Canadian manufacturers could compete on an equal footing with their foreign competitors in domestic and external markets and new manufactured goods could be developed in Canada on a fair basis.

The exploitation of Canada's extensive reserves of natural resources (including ore deposits and water) for export should become a more and more powerful bargaining weapon to obtain concessions for our manufactured products, rather than the main objective of our trade negotiations. Many of these strategic industrial materials will become increasingly scarce in the

world. We might also establish a differential price system that would favour Canadian manufacturers, as has been done with such metals as copper and nickel. Such a policy could be a strong incentive to further processing in Canada. It is both prudent and legitimate to make foreign users' access to irreplaceable resources a negotiable element in trade negotiations to foster the growth of our own secondary manufacturing sector. This reversal in Canadian trade strategy is now possible, and it is necessary to support a new National Policy.

2. *Fiscal and monetary policy*

In a predominantly private enterprise system, the tax system and the climate surrounding it have a considerable influence on business decisions and on the ability of industry to attract capital. These factors have a particularly great impact on industrial R&D activities and innovation since expenditures for innovation are the most volatile type of private investment and so are likely to be the first to be cut when business prospects dim. The high correlation between recessions and the reduction of industrial R&D expenditures may reveal a short-sighted approach to innovation but is a clear indication that these outlays are conceived as marginal.

From the time the White Paper, *Summary of 1971 Tax Reform Legislation,* was published in 1969, uncertainty about government intention prevented industry from preparing long-term plans. It had a particularly adverse effect on R&D funding by industry.

The Hon. E. J. Benson's budget speech on June 18, 1971 helped to reduce uncertainty and improve the corporate income tax situation. The Minister of Finance's statement on October 14, 1971 contained further tax relief. However, the long parliamentary debate on tax reform and the great number of amendments introduced by the government produced new elements of uncertainty. Even Parliament's adoption of the new tax reform legislation has not yet completely clarified this complex situation. Some people argue that this is the price that had to be paid to bring in a major reform that will produce a much better tax system. Others contend that changes have been too extensive or too restricted and that more time should have been provided for their examination.

The Committee's interest in this matter is to invite the government to review the specific implications that the new legislation will have on the industrial innovative process on a continuing basis and to be prepared, when it is found appropriate, to remove impediments to R&D activities and inno-

vation that may appear as a result of the interpretation of the legislation by the proper authorities.

We would like to suggest that before any new tax policy is finally determined, the government should specifically consider its potential impact on the innovation process, on ways of improving it, and in particular on the implications it could have on the ability of Canadian companies to compete in international markets. The tax system, while continuing to serve its main purposes, could also be considered an important ingredient in an overall industrial and technological strategy. For this reason, the Committee suggests that the Department of Finance should always have a top science policy adviser on its staff.

In recent months, the tight money policy has been abandoned. The money supply has been expanded and interest rates have been reduced. The Committee concludes that developments in monetary policy in 1971 have contributed to a favourable climate for economic growth and hopes that they will continue to do so.

3. *Foreign ownership policy*

The factory system was introduced in the first industrial revolution late in the 18th century. The gigantic modern corporation emerged a century later under the auspices of the second major technological revolution. The multi-national corporation came with the third industrial revolution in the late 1950s and with the trading patterns exemplified by the European Common Market.

For Canada, the transition between the continental and international forms of industrial organization was practically imperceptible: the American economic invasion continued. In 1939, for instance, the American share of total foreign investment in Canada was already 60 per cent. Since 1945 it has remained remarkably stable, increasing slowly from 70 per cent to 80 per cent over a period of 22 years. During these years American investments, in absolute terms, rose from $5 billion to $28 billion. They increased at a more rapid rate than British investments (which were once dominant), but less rapidly than capital inflows from all other countries together. The average annual growth rates for the period of 1945-66 are:

U.S.A.	8.1%
U.K.	3.4%
All others	10.5%

These figures are shown in Table 22 or can be derived from it.

Table 22—Foreign Capital Invested in Canada, by Country, Selected Years

Year	United States	United Kingdom*	Other Countries	Total
		(millions of dollars)		
1939	4,151	2,476	286	6,913
1945	4,990	1,750	352	7,092
1951	7,259	1,778	440	9,477
1955	10,275	2,356	842	13,473
1956	11,780	2,668	1,112	15,569
1957	13,264	2,917	1,283	17,464
1958	14,436	3,088	1,481	19,005
1959	15,826	3,199	1,832	20,857
1960	16,718	3,359	2,137	22,214
1961	18,001	3,381	2,224	23,606
1962	19,155	3,399	2,335	24,889
1963	20,479	3,331	2,324	26,134
1964	21,443	3,476	2,448	27,367
1965	23,305	3,498	2,704	29,507
1966	25,724	3,518	2,850	32,092

SOURCE: *Canada Year Book*, 1961 and 1969, and Dominion Bureau of Statistics.
*Includes some investments held for residents of other countries.

Concern about multi-national corporations is now widespread. As the recent Brooks report, sponsored by the OECD, observed:

> The growing power and the high flexibility of multinational firms give rise to problems and conflict between these firms and the host countries, whose authority is often reduced, and especially when the objectives of multinational firms do not accord with the socio-economic goals of the countries in which they operate.... In such circumstances, there is need for reciprocal understanding between the governments of the host countries and the management of multinational firms, to harmonize the strategies of those firms with the goals of the countries in which they operate.[8]

Anthony Wedgwood Benn, formerly Minister of Technology in Britain's Labour Government, recently commented on the power of multi-national firms:

> I doubt whether the political power of governments is any longer expressed through the activities of its national corporations that have gone global. Years ago in the Ministry of Technology, when we were developing an industrial policy to cope with the multinationals, and when Henry Ford came to the office to talk about his future investment plans or Fritz Philips was in London for discussions with IRC, it became apparent that these were heads of sovereign states with whom we had to establish diplomatic relations.

> Last year in talks at the Department of Commerce and State Department in Washington, I discovered that the Americans were only just becoming conscious that the same was true of the relations between the US Federal Government and IBM or General Motors. These principalities were operating there with very few formal links with the administration, save only the need to keep clear of anything that would violate anti-trust legislation.[4]

The rise of multi-national corporations seems to have introduced two different trends in American investment in Canada. It has probably slowed down the flow of U.S. capital in secondary manufacturing industries because the multi-national corporations can readily shift production between subsidiary plants in different countries to gain easier access to other markets. The U.S. DISC (Domestic International Sales Corporations) program is intended to induce U.S.-based multi-national corporations to keep their production in the U.S., or transfer it there, by deferring taxes on much of their earnings from exports. It may affect Canada severely in cutting down the operations of Canadian subsidiaries.

On the other hand, the expansion of U.S.-based multi-national corporations in the secondary manufacturing sector has helped to increase American investment in resource-based industries in Canada. An effective DISC program would continue the trend.

This is another illustration of the need to distinguish between subsidiaries producing finished products and those based on the exploitation of resources if we are to understand the dual aspect of the foreign ownership issue and develop realistic policies to deal with it.

However U.S. policy in the secondary manufacturing sector develops in the future—whether it is based on the concept of multi-national corporations or is aimed at "repatriating" their operations—Canadian subsidiaries that were conceived as miniaturized versions of their parent companies are bound to become liabilities rather than assets, not only for the parent companies but for the U.S. economy as a whole. While American policy might be to let these subsidiaries in their present satellite form gradually die, the parent companies might well prefer to turn them loose to specialize and innovate rather than maintain them in an unprofitable position and eventually lose substantial investments.

For Canada, these subsidiaries may have played a useful role in the past, but with a few exceptions their inability to innovate and the built-in ceiling on their growth now constitute a basic weakness of the national economy; two exceptions are the automobile industry, as a result of the auto pact, and the military area covered by our defence sharing agreements with the United States. As Professor Roger Dehem of Laval University has pointed out:

> In view of what we can observe in countries like Sweden, Holland, Switzerland and other small countries, where large-scale manufacturing has outgrown the small national markets, I suggest that a basic factor inhibiting the growth of secondary manufacturing in Canada is not the smallness of the home market but the *satellitic nature of most of our important firms.* These were established here by big American companies thanks to the Canadian tariff. They were established not as competitors in the world market but as obedient subsidiaries expressly confined to the Canadian market, or, in some cases, to the Commonwealth area.[5]

This "colonial" status of Canadian subsidiaries is now preventing Canadian growth, product differentiation, and innovation. They have even been subjected to American trade policies and monopoly legislation. Before the announcement of President Nixon's new economic policy, a number of U.S. corporations had begun to rationalize the production of their subsidiaries by integrating it with the operations of the parent company. But this is not enough. Such developments can also weaken Canada, as Professor Crookell at the University of Western Ontario observes:

> . . . if [other industries] behave like the auto makers and rationalize operations from a production standpoint only, then another Canadian industry would lose its managerial and professional staff and with them any hope of innovating in the future. To lose the power to innovate in a changing environment is to yield control of the future to those who retain that power.[6]

Canada cannot afford to let subsidiaries in the secondary manufacturing sector die or be crippled. They must be allowed to take part in the innovation operation suggested earlier—they must be allowed to specialize, export, and innovate. The time seems ripe for the Canadian government to take some positive steps in this area; Canada's objectives are increasingly compatible with the protection of the profitability of foreign companies' Canadian investments.

These steps should not be limited to preventing undesirable take-overs. Many other alterations are needed. Special inducements will have to be provided to foreign parent companies to really "Canadianize" their operations in this country. A program along the lines of the United States' DISC may be needed to encourage subsidiaries, as well as other Canadian manufacturing firms, to increase their exports and thus, indirectly, to specialize and innovate. This approach might be more effective in increasing manufacturing and jobs in Canada than the present government program under the Employment Support Bill of 7 September 1971 that merely compensates firms for the loss of exports. Again, how likely are Canadian-owned firms to be able to beat a

foreign-owned firm to a take-over when the foreign company is allowed by its government to deduct interest paid on the money borrowed to make the acquisition as a business expense when it is making up its income tax return? What about the 15 per cent withholding tax, which deters Canadians from borrowing from the so-called Eurodollar and Asia dollar markets? While equity capital flows freely from the United States, Canadian provinces and municipalities are discouraged from selling their bonds on the American market; and many wholly foreign-owned subsidiaries can meet their financial requirements by borrowing on the Canadian market instead of having to sell shares to Canadian residents. It would not seem too much to ask that in the future, all forms of federal and provincial assistance to secondary manufacturing subsidiaries be made subject to satisfactory assurances that these firms will be free to specialize and innovate in Canada and to sell their products abroad like Canadian-owned companies.

While it is not the Committee's responsibility to deal with the foreign ownership issue, we feel that the Canadian government must take steps, as a result of its consideration of the Gray report, to correct these deficiencies and provide effective inducements for foreign parent companies to "Canadianize" their operations. Otherwise the industrial revolution in the Canadian secondary manufacturing sector may fail, in spite of its great urgency. To ensure the viability of this vital sector of the Canadian economy against the negative effects of the international technological race and new trading patterns is an essential national task.

The other side of the foreign ownership issue is related to resource-based industries. Here we encounter quite different policy problems, mainly concerned with the over-exploitation of Canadian resources, the re-cycling of wastes, the development of new uses for primary products, the cost and price policies followed by subsidiaries, and the processing of finished products in Canada for export. Prospecting operations could become joint ventures with government participation so that the extent of Canadian reserves would become public knowledge. Allowances or tax incentives for the development of Canadian resources should be as advantageous to Canadian firms as they are to foreign-based companies. In the case of resource industries, the Canadian equivalent to the American DISC program—or any other form of government assistance designed to foster innovation and exports—could be made to apply only to companies that achieve a negotiated degree of processing their primary products in Canada. The export of raw materials, especially of non-renewable and energy resources, should be determined in the light not only of future Canadian requirements but also of long-term world supplies and needs.

The Committee is not putting forward these suggestions as specific recommendations, but we hope all governments in Canada will seriously appraise them. We are convinced, however, that Canada needs to develop a policy favouring the "Canadianization" of secondary manufacturing subsidiaries and further processing of primary products in Canada if present and future generations of Canadians are to reap the maximum long-term benefits from the national wealth. In this way the solution of the foreign ownership issue would be developed not in isolation but as part of the new overall industrial strategy.

4. *Procurement policy*

Government procurement is another area that has developed its own standards and practices in isolation without anyone really taking into account the important contribution it could make to an overall industrial and technological strategy. At the federal level, the bulk of government purchasing of goods and services is in the hands of the Department of Supply and Services, the Department of Public Works, and some Crown corporations. As a general rule, it appears that no special allowance is made for technological superiority or innovation. The lowest bid is almost invariably accepted if normal technical competence is guaranteed. This is a pity. As the OECD has noted:

> As sizeable customers for the products of many industries, governments have an important influence on the pressures, incentives and barriers to innovation through their procurement practices—in other words, through their influence not on technology itself, but on the market to which technology can respond. By acting as enlightened and forward-looking customers, governments can reduce some of the very considerable uncertainty which, as we have seen, is associated with the market for technological innovation.[7]

All levels of government together, including municipalities and school boards, represent the largest concentration of buying power in Canada. Government purchasing agencies could be trained to assess their future needs in the light of developing technology and instructed to specify product or performance requirements reflecting their assessment. In this way, these agencies would not only be in a better position to improve the productivity and the quality of their operations or to reduce their costs, but this would provide a powerful stimulant for industrial innovation, with beneficial side-effects in the private sector and Canadian export trade, as well as benefiting the government agencies.

The OECD says many countries have used this approach successfully to meet defence and energy requirements. This is true in Canada. Its extension

to other sectors of government purchasing might present difficulties, but the present situation can certainly be improved on. We expect that the central mechanism we will propose will make sure that this powerful instrument of government policy will be used to its maximum potential to promote innovation in Canada.

5. *Competition policy*

A serious deficiency of many Canadian secondary manufacturing industries is their fragmentation into small but unspecialized firms, which cater mainly to the domestic market. Failure to specialize weakens their ability to innovate or to compete in export markets. While this fragmentation has other causes, it may be perpetuated by Canadian competition policy or by the enforcement in Canada of American legislation or the extension of American court decisions to subsidiaries of U.S. companies. One of the best—or worst—examples was the United States judicial order that DuPont had to abandon its arrangement with Imperial Chemical Limited, its British competitor. These two foreign companies jointly owned Canadian Industries Ltd., which had to abandon a whole range of products in Canada to a new company, DuPont of Canada Ltd., in order to conform to the American court order. The Canadian government should take whatever action is necessary to prevent the extraterritorial application of U.S. Law to Canadian subsidiaries of U.S. parent corporations, and in time, no doubt, all countries could agree that their jurisdiction is no more than national.

The Committee has received many complaints from industry about the interpretation and administration of the Canadian Combines Investigation Act. Companies have contended that many industries are too fragmented to develop an innovative capacity or to afford even a minimum critical mass of R&D activities. It has also been argued that the interpretation of Canadian legislation rests on the concept of "free competition" and thus often prevents mergers and specialization specifically designed to meet the problem of scale. To understand the present Canadian situation, the Committee believes, it is necessary to look briefly at its history.

The American legislation, which began with the Sherman Anti-Trust Act of 1890, was designed to outlaw every "combination in the form of Trust or otherwise, or conspiracy, in restraint of trade and commerce or any acquisition, in whole or in part, of a business by another where there may be an adverse effect on competition". Thus, from the start, the American approach was founded on the concept of "free competition", although this may not be apparent in the gigantic corporations that have emerged in the United States in the present century. In Canada, Parliament took a different attitude. Its

legislation was based not on the maintenance of competition but rather on the requirements of the public interest, a much broader concept for appraising business arrangements and practices. For instance, when Mackenzie King introduced the Combines Investigation Bill in 1923 he declared in the House of Commons:

> I notice in one press report it was stated that the Act did not distinguish between good combines and bad combines. Well, that is the very distinction that is carefully made in the definition itself. Any combination, whether it is in the nature of a trust or merger or the result of some agreement, which is carrying on its business in a reasonable way, not operating to the detriment of the public or against the interest of the public, would not come under the important provision of this legislation. . . . The legislation does not seek in any way to restrict just combinations or agreements between business and industrial houses and firms, but it does seek to protect the public against the possible ill effects of these combinations.

This distinction and the wording of the Act clearly called for an appraisal of the economic performance of combines to determine the public interest before they were declared illegal. But the courts refused. They adopted the approach of Mr. Justice I. Hope:

> The Courts should not be called upon to adjudicate between conflicting theories of political economy. . . . As Sir Frederick Pollock once observed shrewdly: "Our Lady of the Common Law is not a professed economist."[8]

On the basis of this attitude, F. A. McGregor, then commissioner of the Combines Investigation Commission, was able to state in 1947:

> The primary purpose of the legislation is, therefore, to thwart every attempt on the part of business groups to deprive the public of its right to reasonably free competitive conditions. . . . It does not impose any responsibility to determine whether increased prices bear a proper relationship to increases in costs or whether individual sellers have made unreasonable profits in the sale of their goods.[9]

Thus, the meaning of "the interest of the public", the expression used in the Combines Investigation Act, was restricted by "Our Lady of the Common Law" to "the protection of the *specific* public interest *in free competition*", to use Mr. Justice C. J. Duff's words. The Canadian legislation, which in its intent and wording had been much more permissive than the American enactments was, in any event, interpreted in exactly the same restricted manner.

A committee appointed to study combines legislation in 1950 tried to restore the broad interpretation that Parliament had approved in 1923. It

proposed the establishment of an administrative board to hear evidence in each trade practice and combines cases and to prepare a report with its recommendations for the Minister of Justice:

> [The report] should reach conclusions on whether or not competition has been restricted or lessened *and whether in the opinion of the board the conditions or practices have operated or are likely to operate to the detriment of the public.*[10] [Emphasis added]

In 1952, the Combines Investigation Act was amended and the Restrictive Trade Practices Commission was created. Subsection (1) of section 19 read as follows:

> The Commission shall . . . make a report in writing and without delay transmit it to the Minister; such report shall review the evidence and material, *appraise the effect on the public interest of arrangements and practices* disclosed in the evidence, and contain recommendations as to the application of remedies provided in this Act and other remedies. [Emphasis added].

But the Commission, in spite of its specific mandate, refused like the courts to "appraise the effect on the public interest". For instance, in a case involving asphalt and tar roofing products, it stated:

> It was argued before the Commission . . . that a combination . . . should not be considered as operating or likely to operate to the detriment or against the interest of the public unless it could be demonstrated that the prices so fixed were unreasonable or that the public suffered in some specific manner. . . . *The legislation has never been construed in this fashion by Canadian courts which have consistently held that the legislation reflects a fundamental principle of our economic system, namely, "the protection of the public interest in free competition.* [Emphasis added.]

Thus the intention of Parliament expressed in the Act of 1923 and in its subsequent amendments has been ignored by the courts and the commission created in 1952. As a result, the concept of free competition on which the American legislation was based has also been applied in Canada, where economic and industrial conditions are completely different.

Recent government proposals on this matter contained several improvements but some of the provisions were strongly criticized by industry. The Committee agrees with the Science Council's comments on their proposals:

> The Science Council urges that . . . it be recognized that specialization and scale have growing importance, and that fragmentation has significant disadvantages in the domestic market. At the same time, the Council notes that the sole criterion is that of consumer benefit. It contends that the survival of domestic industries is at least as significant, and that this should be con-

sidered in assessing ultimate consumer benefit. *Under an enlightened Competition Policy, mergers, joint ventures and other partnership arrangements designed to improve international competitiveness and efficiency should not be discouraged.*[11]

The government proposals did aim to make rationalization of industry and trade easier and to promote efficiencies. But the criterion of consumer benefit was too narrow a basis for the proposed appraisal of business arrangements and practices, which must include their effect on exports, incomes, and jobs. We have here another example of how the Canadian government, in its pursuit of a specific mission—the protection of consumers—can attempt to serve this purpose in isolation, without taking proper account of the imperatives of a broad industrial and technological strategy.

6. *Standards policy*

The efficient operation of secondary manufacturing industries requires the existence of a system of engineering, design, and industrial standards, not only to protect the users from health and safety hazards, but also to ensure uniformity and quality of products, promote interchangeability, and discourage the uneconomic proliferation of products.

A good system of national standards can also encourage technological innovation by requiring higher levels of quality and performance. (It is of course important to be sure that arbitrary standards do not impede technological progress and for this reason performance standards or functional standards are always preferable.)

The general situation of standards in Canada is less than satisfactory. The Committee has been told, for instance, that there are no effective regulations governing the trucking of hazardous products. We are concerned by the system of safeguards defined and enforced by the Atomic Energy Control Board. We also have the impression that too many government agencies and departments are involved in establishing regulations, codes, and standards and that there is not enough collaboration between them. If these responsibilities cannot be integrated in a single agency, such as the Department of Consumer and Corporate Affairs, there should be at least an inter-departmental committee, responsible to the minister of that department, so that the various agencies can consult each other periodically, co-ordinate their activities better, detect undesirable gaps, and decide which department should fill them.

All regulations, codes, and standards should also be reviewed on a continuing basis to make sure they do not freeze technology and prevent design improvements.

The Standards Council of Canada was established by Parliament in October 1970 to provide a comprehensive national standards system and to make sure that Canada participate effectively in international standards activities. This participation is particularly important to the export of manufactured products. The Committee suggests that it is urgent to get the council fully operational so that Canada can get involved in the rapidly expanding activities of the International Organization for Standardization and the International Electrotechnical Commission.

The Preparatory Commission for Metric Conversion has now been established to plan for the eventual adoption of the metric system in Canada. The United Kingdom is expected to complete conversion by 1975 and virtually all of the other remaining countries still using Imperial measures have declared their intention of following suit. The United States is also contemplating a switch to the metric system. Because of the growing use of metric units around the world, as well as their inherent simplicity and consistency, the Committee believes that Canada should convert to the metric system as soon as practicable. Metrication has become inevitable, and delay will eventually hamper Canadian export of manufactured products.

7. *Industrial relations and manpower policy*

The Committee has repeatedly affirmed its conviction that a major conversion of the Canadian secondary manufacturing sector has become urgent if it is to develop a solid basis for innovative capacity and that the flow of technological innovations in all Canadian industries should be significantly increased if the national economy is to be sustained and strengthened to cope with emerging world trends.

However, technological change entails benefits and costs for both labour and capital, as well as for the economy and society as a whole.

On the benefit side, business stands to increase its profits, labour to improve its real income and its working conditions, and the economy to strengthen its competitiveness and its productivity. As a result, about half of business net profits and a smaller share of rising labour income contribute to higher government revenues.

On the cost side, the introduction of technological innovations is a risky venture which may mean a negative income for the firm and the loss of jobs and the obligation to move to another occupation or locality for a number of workers. In an address to a meeting of the Ministers of Labour of Canada held in Montreal on November 1, 1971, Senator Carl Goldenberg said:

I now turn to another major cause of current worker unrest: insecurity resulting from the fear of displacement because of technological change. Men trained in particular skills, which they expected to use for the rest of their working lives, may find, at an age when it is difficult for them to be retrained or to obtain new employment, that their skills are no longer required. It is anxiety for job security and fear of unemployment that lie at the root of some recent major industrial conflicts in Canada and the United States and threaten continued serious unrest unless the problem is dealt with fairly by employers, unions and government.

There is fortunately a growing realization that, before introducing changes which will displace or otherwise materially affect its workers, it is the responsibility of management to give adequate advance notice of the proposed changes, to consult and seek agreement with the union representing its employees on the best means of adjusting to the situation, and to provide for retraining or relocation or compensation for the employees to be displaced. This is now provided for in some collective agreements and, to a degree, by law. The underlying principle has been well stated by a leading authority, Professor Kahn-Freund of Oxford University, in these words: "If an employee's property in his job should be, in effect, expropriated as society seeks more efficient forms of production, he is entitled to receive compensation."

The Committee agrees that workers should be adequately protected against the adverse effects of technological change. They are entitled to notice and consultation and, in the case of organized employees, to negotiate by collective bargaining the procedures to meet the unfavourable impact of such change. This, however, raises the question of what form government intervention should take to protect the workers adversely affected by technological change.

At one extreme, governments can leave private industry free to innovate when it chooses, within the limits of collective bargaining, and decide to assume themselves the full responsibility, financial and otherwise, for protecting the workers victimized in one form or another by technological change. Under such conditions, innovations would not be discouraged. Its net benefits would be shared by industry, labour, the economy as a whole and the government sector. But the government would bear the total burden of technological progress, in so far as it affects the workers and it might not always be in a good position to meet that responsibility alone and effectively.

At the other extreme, governments could force industry to give long advance notice of its intentions to introduce any technological change, allow the unions full rights for mid-contract negotiations before or after such a change is introduced, and rely exclusively on collective bargaining to determine how the adverse effect of technological innovations should be shared

between industry and labour. Governments could even, through mandatory provisions, place the full burden of the negative impact of technological change on industry. Such an approach would become a great impediment to industrial innovation and would cause serious damage not only to the national economy but also to Canadian workers themselves.

Between these two extremes, there are, of course, better and more practical alternatives which can reconcile the protection of workers, the responsibility of management in this area and at the same time minimize the impediment to the industrial innovative process. The Committee does not intend here to examine these possible alternatives. They are now being studied by the Canadian government and Parliament will probably have to examine concrete proposals in the near future.

We merely want to underline the fact that the public interest has two specific requirements in this area: to promote a high flow of industrial innovations, which would benefit the economy as a whole, and to protect the workers against the adverse effects of technological change. These two requirements have to be reconciled. Since the Committee finds that innovation in Canadian industry is essential to economic growth and should not be blocked, it urges that collective bargaining in the matter of technological change should not relate to the introduction of the proposed change as such but to the procedures and measures necessary to assist the employees affected to adjust to the effects of the change. Such measures call for action by the employer, by representatives of the employees and government.

Our concern is that the Canadian government, while pursuing the most desirable objective to protect the workers, may ignore the other requirements of the public interest. We believe that in this specific area of public policy, as in many others, there should be proper mechanisms within government charged with the responsibility for reconciling particular policy objectives in the light of an overall industrial and technological strategy. Otherwise, conflicts will arise inevitably and often inadvertently and ideal compromise solutions will not be developed. In this context every sector of the Canadian economy, including labour, stands to lose.

8. *Patent policy*

Industry's purpose in funding R&D activities is to produce successful innovations and so gain benefits in the market place. The mere fact of being the first to introduce a new product or process gives a firm a certain lead time in which it can enjoy a profitable position on the market. That time can be extended by an effective patent system because it makes imitation more diffi-

cult and in many cases impossible. Thus, the public interest involved in a good patent system is not primarily protection of the rights of the inventor or the patentee: he may not be capable of developing his invention, he may even object to its use. It should be primarily to protect the exploitation of an innovation.

The present Canadian patent legislation does not meet this requirement. According to the Patent and Trademark Institute of Canada, it is "... almost unique in providing for the grant of a patent to the first inventor rather than to the inventor who first files a patent application".[12] Dr. Donald A. Chisholm, in his address to the Professional Engineers of the Province of Ontario, claimed that the Canadian Act "... makes invention public but actually restricts innovation. It further restricts invention to a very narrow sub class of technical matters".[13] It has also been contended that the American legislation discriminates against foreign inventors, including Canadians, in apparent violation of the reciprocity provisions of the international convention.

The Patent and Trademark Institute also criticized the interpretation and administration of the Canadian Act:

> In the years since 1947 the uncertainty surrounding validity of patents has continued to grow at an accelerated pace. New grounds of invalidity have been established in our courts and already recognized grounds of invalidity have been given an increasingly broader field of application. This is most apparent in relation to that aspect of "invention" which is referred to as "utility".[14]

The same criticism has been made of the courts' definition of an invention. Litigation has been found lengthy and costly too. The institute cited the case of Radio Corporation of America v. Philco Corporation (Delaware) involving some of the basic technology of colour television. The Supreme Court of Canada ruled on this case in 1966; the patent applications had been filed in 1951.

The institute also noted that the rapidly growing number of applications and their increasing complexity have seriously strained the administration of the system. It estimated that "The average length of time for an application for patent to be pending in the Canadian Patent Office in the more complex fields such as electronics and organic chemistry where there is no conflict is three to four years".[15] The patent office has tried to speed up its procedures and has increased its examining staff. The institute has estimated, however, that computerized information retrieval techniques could save at least 25 per cent of the 170 examiners employed by the office at that time. The cost would be about $70,000 a year.

The Committee was told that " . . . West Germany, Holland, the Scandinavian countries and France have in fact recently overhauled completely their patent statutes in an effort to meet the challenge presented by the mushrooming expansion of technology".[16] In Canada, however, no legislative changes followed the report of the Royal commission on Patents, Copyrights and Industrial Design, presented almost 15 years ago. In 1966 the government requested the Economic Council to make another study of the Canadian patent system. The council presented its report, including a series of recommendations, in January 1971.[17] No legislation based on these recommendations has yet been introduced in Parliament.

The Committee believes that a substantial revision of the Canadian patent legislation and of its administration is long overdue. If the new system could be centred on the protection of an innovation rather than on inventions that may never be exploited and if the granting process could be speeded up, it could greatly encourage the industrial innovative process and, by implication, the R&D effort of Canadian industry.

9. *Regional expansion policy*

It appears to the Committee that a policy designed to distribute industrial growth more evenly around the regions, desirable as it undoubtedly is, should be conceived within the framework of an overall industrial and technological strategy. For instance, using government subsidies to destroy or weaken firms well located in one region by creating new competitors artificially located in another is not in the long-term national or regional interest. These artificial growths can damage prosperous areas without establishing a solid basis for industrial expansion in less-developed regions, since they cannot be subsidized permanently. In Canada and elsewhere experience shows that this kind of approach leads to a waste of public funds, rising expectations, and eventually bitter disillusion in the areas eligible for special assistance.

The Committee believes that the Department of Regional Economic Expansion can continue to play a most useful role within the framework of the proposed new National Policy, provided its activities are supported by a realistic research program. The department should require firms seeking assistance to specify what competitive advantage they expect from establishing a factory in the location chosen, and should use its own researchers to determine if the expectations are justified. Such studies might delay the department's actions but enable it to attain its long-term goal more effectively.

10. *Pollution policy*

The new Department of the Environment has been given the specific responsibility of fighting all forms of pollution, including industrial pollutants. This mission, however, raises several questions that might not be properly considered in the haste to take action to calm growing public concern in this area. The quickest way to create the impression that something is being done is for the government to issue a set of regulations to curb what are thought to be the sources of pollution, to impose heavy fines on firms that do not respect the standards, and thus to rely on industry to pay the cost of finding and implementing effective methods to comply with government regulations.

But quick and apparently easy solutions are not always best. First, there is the problem of preparing proper regulations that will cover the real causes of pollution, that will not impose uselessly strict and expensive standards, and that will not make the situation worse than it is. This raises the complex question of a national system for environmental policies, which cannot be adequately organized without a large and continuing program of scientific activities to complement the scientific and technological information already available in the world. Otherwise, dangerous and costly mistakes can be made. The Committee believes that the Department of the Environment does not have carefully thought through objectives or a coherent program at the moment.

For instance, in June 1970, when the Department of Energy, Mines and Resources, which was then responsible for water pollution, expressed its intention of completely banning the use of phosphates in detergents, it was widely known that industry intended to use a substitute called NTA to comply with the new regulations. The department apparently ignored, however, the fact that preliminary studies done in the United States and Sweden showed that the new substance might be dangerous for humans, while phosphates were not. This story will be examined more completely when the Committee deals with social innovation.

The almost complete ban on DDT offers another good illustration of the same problem. We are now finding eminent spokesmen who question the ban on DDT. For example Norman Borlaug, the U.S. Agrologist who won the Nobel Peace Prize for developing high yield grains, is quoted as saying:

> The safety record of DDT is truly remarkable. There is no evidence in man that DDT is causing cancer or genetic changes.[18]

This remark is representative of the concern of the less developed countries (LDCs) as noted by a recent authoritative survey on environmental pro-

grams: "Measures relating to DDT afford a striking example. The concern of the United States and many other advanced industrial societies to curtail the use of DDT and counteract the consequences of its prior use strikes no responsive cord in the LDCs. They are apprehensive lest they be deprived of DDT, and they are making their apprehensions clear. On the present evidence, nothing will reconcile them to such a deprivation except a substitute at least as effective, safe, easy to handle, and inexpensive as they have found DDT for the purposes to which they attach primary importance, notably antimalarial and other health campaigns and improved yields in their agriculture."[19]

Thomas S. Jukes, Professor of Medical Physics at the University of California in Berkley, has recently written in defence of DDT and made the case for resisting attempts in the United States to ban it. He claims that:

> The defence of DDT is vitally important because the ban would be against the most basic human right—the right to be protected against deadly disease.[20]

However, Canada followed the example of the United States and imposed an almost total ban on DDT in 1969. This ban, which has been eased since, caused substantial harm to industry—farmers in particular—moreover, it induced the chemical industry to develop a whole new range of substitutes, such as phorate, demeton, parathion and ethion, whose side effects may prove to be more harmful than DDT's and which will certainly have to be tested extensively. One report states:

> The toxicity of these latter pesticides, which have been proposed as substitutes, are higher than that of DDT, but their persistence is less. Therefore, in order to obtain the same degree of insect control as previously achieved with DDT, several applications of the less-persistent insecticides must be sprayed on the same area.[21]

These developments may convince the government to be more careful before issuing new regulations for the control of pollution. They may also prompt various government agencies to launch their own research and assessment programs, as the Department of Agriculture is now beginning to do for DDT substitutes. The result of these new rounds of research and assessment may well be to create more confusion and duplication of effort, with an accompanying waste of funds and bad allocation of scarce R&D personnel.

While the government strives to prepare a proper set of regulations for industrial pollution, which is bound to take a long time given the difficulty of the task, is it fair to oblige individual firms to pay the cost of finding and implementing ad hoc solutions? This question has not been properly debated

in Canada. And yet the cost might represent a heavy burden on a whole range of industries that are already experiencing financial and structural difficulties. During its European visit, the Committee noted that the Swedish government was taking a different approach. It had created an elaborate administrative machinery to study and solve pollution problems. It was designed to work in close collaboration with industry and assist it in developing new technology to minimize the cost of pollution abatement.

We think such an approach may be more beneficial for the country as a whole than the negative and punitive attitude emerging in Canada. Instead of a new government impediment to industrial innovation, it may lead to new opportunities for profitable innovations that can be exported abroad. We find, therefore, that if the Department of the Environment and other government agencies involved with the pollution problem were to develop their policies within the framework of the industrial and technological strategy we propose, they might better serve their specific missions, minimize the cost of combating pollution effectively, and at the same time encourage the flow of industrial innovations in Canada.

CONCLUSION

This broad review of the public environment surrounding industrial innovations and R&D activities has shown much that is rather unfavourable at present in Canada. Most of the policies we have examined produce side effects that are harmful to the industrial innovation process while serving their main and unconnected purposes; in fact their harmful effects are generally overlooked in the places where the policies originate. We have concluded that if these side effects were considered in advance it should be possible to formulate policies that would have minimally negative impacts on the general economic climate, industrial innovation, and R&D activities, or even influence them positively, without detracting from their main goals and in some cases even serving them more effectively.

The problem begins when policies are formulated in government departments and agencies that have no science policy advisers to help them consider the impact of their decisions on the economy and the industrial innovative process. Then there should be a central machinery to check a policy's probable effect on innovation, discuss alternatives designed to improve that impact with the department concerned, and in cases of disagreement, report its findings and make its own recommendations to the Cabinet committee dealing with science, technology, and innovation matters.

At the moment there is an embryo machinery called the Interdepartmental Committee on Innovation. It is doubtful, however, whether this committee has sufficient scope or authority to do the job.

We believe that these two gaps in the process should be filled if the public climate for economic growth and industrial innovation is to become more favourable.

The Committee therefore recommends:

1. That all government departments and agencies which can have a significant but indirect impact on the industrial innovative process while serving their main missions, acquire the services of science policy advisers whose responsibility would include drawing attention to that impact when administrative decisions are taken and new policies are formulated;

2. That the scope, composition, and authority of the Interdepartmental Committee on Innovation be enlarged to review, appraise, and discuss with the departments and agencies concerned the implications on the innovative process of their decisions and policies and, if necessary, to present recommendations to the Cabinet committee responsible for science policy; and

3. That the Minister of State for Science and Technology be responsible for reporting to Cabinet the recommendations accepted by the Cabinet committee on these issues and that his staff provide the chairmanship and the secretariat of the interdepartmental committee.

We would expect the various departments and agencies concerned to be represented on the interdepartmental committee by their science policy advisers. This would ensure their more interested and active participation. Co-ordination and integration often remain empty words when their object, as in this case, is only marginal to the members. What is more, the responsibility for the policy issues to be reviewed is widely dispersed within the government. For both these reasons it is important that the leadership of this review process be strong, impartial, and yet deeply committed to the promotion of industrial innovation and the removal of unnecessary impediments in the public sector. This is why it is proposed that the prime responsibility be assigned to the Minister of State for Science and Technology and his senior official.

Government departments and agencies whose draft policies would be submitted to this outside review might well resent it as an intrusion and interference. On the other hand, if there is no systematic attempt to harmonize policies serving other ends with the requirements of an overall industrial and technological strategy, the public environment may become increasingly

hostile to industrial innovations and R&D activities instead of promoting them. Indeed, a favourable climate in the public sector could do more to encourage these industrial activities than millions of dollars in government direct assistance programs, just as the beneficial effects of these programs can be nullified by an inimical environment. The procedure envisaged in the Committee's recommendations would enable the government as a whole at least to know how its policies affect the general climate for innovation and how they could be changed to improve it.

NOTES AND REFERENCES

1. Sir Alec Cairncross, "Government and Innovation", *New Scientist and Science Journal,* 2 September, 1971, p. 505.
2. J. Herbert Holloman and Alan E. Harger, "America's Technological Dilemma", *Technology Review,* July 1971, p. 40.
3. OECD, *Science, Growth and Society: A new perspective,* Report of the Secretary-General's Ad Hoc Group on New Concepts of Science Policy, Paris, 1971, p. 94.
4. Anthony Wedgwood Benn, review of Nicholas Faith, *The Infiltrators,* November 7, 1971.
5. Roger Dehem, "The Economics of Stunted Growth", *Canadian Journal of Economics and Political Science,* November 1962, pp. 509-510.
6. Harold Crookell, "From Auto Pact to Appliance Pact—Steps Toward a Legislated Economy", *The Business Quarterly,* University of Western Ontario, Spring 1970, p. 70.
7. OECD, *The Conditions for Success . . . , op. cit.,* p. 133.
8. Justice I. Hope,
9. F. A. MacGregor, Canadian Journal of Political Science and Economics, 1947.
10. Committee to study Combines Legislation, *Report to the Minister of Justice,* Queen's Printer, Ottawa 1952, p. 34.
11. *Innovation in a Cold Climate, op. cit.,* p. 29.
12. Senate Special Committee on Science Policy *Proceedings,* No. 64, June 17, 1969, p. 7786.
13. Donald Chisholm, "Thoughts on Innovation in Canada", *op. cit.,* p. 3.
14. *Proceedings* No. 64, *op. cit.,* p. 7788.
15. Ibid., p. 7791.
16. Ibid., p. 7790.
17. *Interim report on intellectual and industrial property,* Economic Council of Canada, January, 1971. See also Andrew H. Wilson Background Study for the Science Council of Canada, Special Study No. 11, *Background to Invention.*
18. Henry F. Heald, "DDT not villain first thought to be", *The Ottawa Journal,* November 20, 1971.
19. "*Man's Impact on the Global Environment*", The M.I.T. Press, Cambridge, 1970, p. 254.
20. "DDT—The Poor Man's Chemical and Life Saver of Emerging Chemicals", Thomas S. Jukes, *The Ottawa Journal,* August 12, 1971.
21. *Man's Impact on the Global Environment*", *op. cit.,* p. 281.

17

INDUSTRIAL INNOVATION AND DIRECT GOVERNMENT ASSISTANCE

The gap between the present level of industrial R&D and the desirable target that should be attained by 1980 is so big that the Canadian government will have to intensify its direct assistance and, more importantly, change the form and emphasis of its support, at the same time increasing the amount of R&D performed in industry and financed by government departments and agencies.

The principle involved in direct government support for the industrial innovative process is hardly questioned any more. It is now widely recognized that public authorities have a direct interest in assisting this process, not only to meet their own needs but also as part of their overall responsibility to sustain the national economy and as compensation for the returns they get, through taxes, from profitable innovations.

While expenditures related to the innovation process probably constitute in many cases the most risky type of private investment, the technological multiplier is likely to lead to the highest overall economic growth. In other words, the benefit-cost ratio in supporting the industrial innovative process is usually smaller for the firm than for the economy as a whole. Under such conditions society stands to gain if public support is extended up to the point where the marginal social costs and benefits are equal. And if governments are expected to support curiosity-oriented basic research totally in order to meet their obligation to contribute to the international pool of scientific knowledge, why should they not assist the industrial innovation process, which can, when successful, contribute significantly to the national advantage by sustaining economic expansion, providing better job opportunities, and raising living standards. These arguments are now generally accepted. The main

differences that exist between advanced industrialized countries are in the level of direct government support and its form, whether services or fiscal incentives.

ELEMENTS OF STRATEGY

It should now be clear that Canadian industry has not been highly innovative and that its performance of R&D has been poor. The relative weakness of the private sector is so great, in fact, that the Canadian government may have to do more than public authorities in most other countries. But if intensified public effort is to yield its maximum benefits, it should rest on a coherent strategy inspired by the new National Policy and intrinsic requirements of the innovative process itself.

In terms of national objectives, the first priority of direct government support should be to establish and maintain the international competitiveness of products fully manufactured in Canada.

This means that resource-based industries that neither process their products nor sell them in Canada for further processing should receive a comparatively low priority. Governments should maintain, even extend, their participation with private enterprise in geological surveys and prospecting for the discovery of more reserves. But the Canadian government should concentrate its assistance on projects designed to find new uses for primary products, which provide new opportunities for manufacturing in Canada, and so extend the market potential.

The government should adopt both a passive strategy and a positive one. Some people argue that those in government responsible for direct assistance to industry should work from a detailed set of public priorities and select certain types of innovation and R&D projects for support and ignore others. The Committee does not agree. Selectivity is essential, of course, but in being selective about what it supports, the government must take care not to usurp the judgment of the individual firm about which projects are likely to result in profitable, marketable products and services in the long run. The government is not generally better equipped than private management to select the specific areas where successful technological innovation is possible. The innovation process is complex and uncertain enough that it cannot be effectively planned by outsiders. As Sir Alec Cairncross has pointed out:

> The last thing that governments are equipped to do is to promote industrial innovation. They can never spot the real winners because they are far too clumsy, ignorant and bureaucratic. Instead they are likely to go in for expensive prestige projects that tie up scarce design teams until another government comes in and scraps the whole affair.[1]

The innovative firm, like the brilliant scientific discoverer, should be free to select its own field of endeavour; and within certain limits, the government should stand ready to assist if need be, whatever specific project the firm wants to develop.

The government cannot support every proposal submitted by industry. It would be quite unjustified to use public funds to support R&D programs that have no chance of success, or of being exploited in Canada, and when no other comparable benefits accrue to the country.

Government administrators and politicians often forget that the opportunity for profits is the keystone of industry's willingness to innovate, and government policies must recognize this, if they want a strong and internationally competitive Canadian industry. We have already noted the significance of tax, tariff, patent, competition, and trade policies to this aim.

Generally, therefore, in deciding whether or not to support proposals from industry under its direct assistance programs, the government should first assure itself that the projects have substantial profit and market potential and that the firm's management is competent to carry the project through to a successful conclusion. The government should also be satisfied that the benefits to the Canadian economy and contributions the project may make to other government objectives justify government support.

In addition, the government should identify possible opportunities and draw these to the attention of firms whose innovative performance is weak. Private management is not always eager to innovate. The government should continuously review the intensity and effectiveness of each industry's innovative effort. It should establish an R&D and innovation audit system designed to reveal areas of inadequacy, which would enable it to have discussions with industries where anomalies appear and consider why their innovative effort is weak and how it could be improved.

This approach is further justified by two factors. One, the most striking feature of the new technological revolution is its widespread and all-embracing character. In the future, all industries and services will be deeply affected by rapid technological change and the potential for innovation will be extensive. Two, the Canadian economy has developed a fairly solid infrastructure and has access to ample reserves of diversified raw materials. Many avenues for innovation and growth are open to it. These opportunities should not be restricted by preconceived government views that might weaken the innovative effort of aggressive firms or even divert it into unprofitable areas of endeavour.

There are a number of views on the launching of major R&D programs. Some people argue that such programs, involving high technology and pre-

sumably financed by the government but contracted out to industry by various departments, would be the best and most exciting way to promote R&D and innovation in the private sector. The argument advanced to support this theory is that big ventures are necessary to develop large teams of competent technologists and keep them in Canada. It is also argued that the spin-off effects and the technological multiplier leading to other innovations are often greater than the direct results of the programs themselves. This theory sounds attractive, because the strategy involved is fairly simple: even the selection of programs is not too important. It may even be decided to go to the moon if the indirect innovations and benefits on earth exceed the cost of the project. But recent evidence shows that the reality has not been as profitable as theory said it would be. There is a growing consensus in the United States that government funding of large military projects has not strengthened civilian industry as it should according to the "spin-off" hypothesis, but on the contrary has weakened and distorted it. As a result, the U.S. government is seriously considering offering broad direct support for R&D activities in the civilian manufacturing sector. An article by J. Herbert Hollomon and Alan E. Harger points out that the U.S. government concentrated the national R&D effort in defence, space, and atomic energy for military purposes while most Western European governments and Japan were centering their effort in civilian industry:

> This disparity in technical effort, existing for more than ten years, may have begun to be reflected in our trade with Europe and with Japan. Consider the trade balance in the technologically intensive products of chemicals, machinery, electrical equipment, transportation equipment and instruments. In 1968, the United States had a favorable balance of trade of these products with Europe of $1.5 billion. From 1962 to 1968, however, the rate of growth of imports of these products from Europe averaged 20 per cent, and the rate of growth in their export from the United States averaged only 9 per cent. During this same period, the United States' trade balance with Japan in these products turned from a $300 million surplus to a $500 million deficit. While United States imports from Japan were growing at 32 per cent a year, United States exports to Japan were increasing at only 7 per cent a year. If the trend continues, Boretsky estimates that by 1973, in technologically intensive products alone, there will be a trade deficit with Europe of almost $2 billion. The situation with respect to Japan is even more disturbing: he estimates that the United States "technological" trade deficit to Japan will be almost $5 billion by 1973. ... it appears that in the United States we have substantially under-invested in the kinds of technical effort that are necessary for the improvement of our industrial output and the quality of our life.[2]

Obviously, Canada cannot afford to repeat this American experience.

Where the total R&D effort is low in absolute terms, big programs require a disproportionate share of the available funds and manpower and when they fail, they are likely to be national catastrophes. Teams of scientists and engineers have to be disbanded and the public is led to believe that money devoted to R&D is wasted. Moreover the chances of success for small countries are limited. Most huge projects involve national prestige and require large markets. This is a sector where big powers want to be "second to none" and smaller nations are seldom in a position to meet that competition.

Experience in Canada and elsewhere supports these observations. The most recent case is the hydrofoil ship *Bras d'Or*. The Arrow project was also a sad affair. Even if it had been a technical success, the mission to be served by that plane was so important to military security and national prestige that the Americans could not have afforded to rely on foreign suppliers. (Since then, however, Canada has been successful in developing new types of small aircraft). We are finding that it is not easy to sell nuclear reactors abroad in competition with bigger nations. We have had to admit that we could not build communication satellites as cheaply as the Americans, mainly because of our limited requirements and the impossibility of developing an export market. While it may be possible to launch major programs in co-operation with other countries, the experience of the British and French in developing the Concorde has shown that international co-operation in the sector of industrial innovation is not easy to achieve and how tremendously important it is that long-run market potential should be sufficient to justify the risks of failure and the costs.

Big programs of this nature should not be excluded *a priori* from the Canadian scene, but all their implications should be carefully and objectively appraised before public funds are allocated to them. A primary criterion for undertaking such projects in Canada, rather than acquiring the necessary technology from abroad, should be the potential for long-run government and private markets that will return good profits to the companies involved. Thus, if such projects are supported, there should be a continuing independent evaluation by a separate agency to be sure they are not funded beyond the point justified by the likelihood of success or market potential. In any case, big programs certainly should not form the primary basis of government strategy for helping to build and use innovative capacity in Canadian industry. The national innovative capacity is improved more by many "mini-inventions" than by a few spectacular major inventions. The Committee concludes that concentrating investment in major programs is too risky a strategy for a country the size of Canada.

Industrial R&D is only the first phase in the innovation process. The purpose of public support is to promote a high flow of successful innovations, not simply to fund laboratory research. The invention has to be transformed into an innovation, including its introduction on the market. This phase should still be called development work and it is often less risky but more expensive than R&D in the usual sense. It is also more crucial. When it fails, even the best and most fruitful R&D effort is completely wasted. As Dr. Chisholm has put it:

> ... the road from invention to innovation and presumably that dirty word profit, is a long one and an expensive one. First the idea must be reduced to practice, then a use of the idea must be selected and a manufacturable design produced, a manufacturing facility built, a marketing and distribution organization found or built, and finally if customers appear, an innovation has occurred. Actually innovation can occur anywhere down that chain but our folklore concentrates on the eureka phase.[8]

Government assistance is needed for the rest of the innovative process, though the form of assistance will not be the same.

Government strategy should also recognize the obvious fact that in our present economic system, most industrial innovations must be introduced by private firms. Empirical studies show that the process leading to innovation in the marketplace is practically indivisible and that success largely depends on continuity, with the possible exception of fundamental research. This means that the ideal location for the performance of industrial R&D is the private firm. That does not eliminate government laboratories or even universities from this area of R&D. It may be desirable for these two sectors to complement what is being done by the private sector; it may even be necessary for them to play the major role on behalf of industries composed of a large number of small firms, such as agriculture and fisheries. But even then government laboratories must play the smallest possible role. They must respond to clearly identified industrial needs. They must also maintain close liaison with industry because person-to-person contacts have been found to be the most effective means of transferring technology.

Direct government support for industrial innovation should be flexible enough to vary in form and in degree from industry to industry, from firm to firm, from one type of innovative strategy to another, and from one state of the innovative process to another. For instance, in industries with a large number of small firms, such as agriculture, the government may have to assume the full cost and an important portion of the performance of R&D if such activities are to be undertaken at all. When an absorptive strategy,

that is, product improvement, is applied, especially in industries composed of a small number of large firms, public assistance, if it is required at all, should be concentrated on the last stage of the innovation sequence and take the form of direct or guaranteed loans or equity capital. Between these two extremes of full financing by public funds and intramural activities on the one hand, and loans and equity capital on the other, the government can also use special procurement policies, tax concessions and R&D contracts or grants as other possible methods of meeting different specific conditions.

The flexible strategy we propose requires a high degree of administrative integration. If each method of assistance is assigned to a different agency, gaps, duplication, and different administrative procedures and standards will almost inevitably develop. Such decentralization is bound to make an already complex area of policy even more complicated, and to make the administration of the various programs more costly and less effective. Administrative integration would lead to the development of special expertise in this area, something that would be as useful to the private companies dealing with government as to the government itself.

DIRECT FINANCIAL ASSISTANCE

Most countries have found that the promotion of a favourable public and private environment and the provision of specific services were not enough to produce an adequate level of R&D activities and innovations in the industrial sector. They have felt that some form of direct financial incentives was also necessary. There are a variety of financial incentives to choose from.

A few countries have limited their support to tax relief. The United States has relied almost exclusively on government R&D contracts to industry but is planning to broaden its support. France, Great Britain, and Sweden have followed a broader approach.

Canada really began to stimulate the R&D efforts of individual firms in 1962 by providing financial assistance through a special tax incentive program, which was abandoned in 1966. The Canadian government started to offer direct grants to industry in 1961 and, in the latter part of the 1960s, put almost all its emphasis on this type of assistance. As Table 24 shows, the grants offered by NRC and the Department of Industry, Trade and Commerce increased from $30 million in 1966-67 to an estimated $91 million in 1971-72. Canada certainly has the most elaborate system of grants to industry among all advanced countries. And yet, in 1967—the most recent

year for which international comparisons can be made—Canadian industry was still funding a high proportion of the R&D it performed: almost as high as Germany and significantly higher than Sweden, the United Kingdom, France, and the United States (*Table 12, Chapter 6, Volume 1*).

There is clearly something wrong with the government approach to the support of R&D and innovation in industry. The Committee has already indicated a major weakness in the area of government contracts. But there are other deficiencies and gaps that need to be examined.

1. *Existing grants programs*

As the Committee indicated in Volume 1, there are far too many grants programs. Created more or less in isolation, they contain widely varying terms and conditions and raise problems of overlapping and demarcation, especially where financial terms differ significantly. For example, the boundary between research and development is not always easy to define and yet marked differences in conditions make it necessary to draw this distinction and decide between support under IRAP and PAIT or under DIR and DIP. Under existing rules, both IRAP and DIR can support development projects, the only limitation being the availability of funds. These shortcomings are further increased by the fragmentation of program management between different agencies and within individual agencies.

These deficiencies are the result of the absence of a coherent strategy for the overall level of government direct financial assistance, its distribution, and its form. The Committee notes with satisfaction that the increased support since 1966-67 has come mainly from PAIT and IRDIA. This concentration of effort is a step in the right direction. It should now be followed by further integration as well as by simpler and more uniform administrative practices.

The time has come to integrate all specific R&D incentives—DIP, PAIT, IRAP, DIR—into a single multi-purpose program. It should be sufficiently flexible to meet all reasonable special requirements. This would eliminate demarcation and overlapping problems, ensure equitable and consistent treatment of all industries, permit the establishment of an effective system of priorities, and lead to more effective, less costly, and less confusing administration.

This integrated program should be able to offer consolidated grants covering all the facets of R&D, the whole sequence of the innovative process including market assessment and preproduction engineering, excluding only the cost of acquiring capital facilities and the establishment of marketing and distribution systems for introduction of the new product or process on the market.

It would cover both main parts: assisting private firms to develop a specific R&D capacity they need and helping them to use this capacity to produce successful innovations. The program might even offer grants for the purpose of transferring QSEs from government laboratories to industries or for work needed by a company that can be done better or at a lower cost by specialized private firms or universities.

The strategy to be adopted should be broad but at the same time specific. New products and processes related to secondary manufacturing should get first priority. The integrated grants program should put the emphasis on development rather than research and require that the eventual innovation take place in Canada or that at least comparable benefits accrue to this country. Within the limits of these broad priorities and requirements, no industrial sector and no project should be excluded *per se*. The administration of the program should not be passive; as well as receiving applications it should invite proposals from industrial sectors where innovative performance is weak. In fact, this active role should be emphasized. The reinforcement of weak sectors might be precisely the area where maximum gains can be achieved.

But the strategy must be selective as far as the area and degree of assistance are concerned. It is as important to help private companies develop a good R&D basis as to assist them in using it. As well as supporting specific projects, the program should have the flexibility to provide 50 per cent of the cost of developing the basis for R&D during a period of five years. (Empirical studies have shown that "R and D groups tended to be most productive after four or five years' existence".)[4] However, firms with no innovative experience and no R&D base should be encouraged to begin by defining an absorptive strategy and building their capacity accordingly. This strategy is less risky and costly than the offensive strategy, and serves as a useful preliminary to any offensive innovation program developed later.

The administrators of the program should develop their own criteria and priorities for the selection of R&D projects to be supported and the degree of assistance they should receive. They should first require private firms to present their own benefit-cost ratio and evaluation of the success potential of the innovation. The administrators should also develop techniques for measuring the social benefit-cost ratio and evaluating the chance of success. These measurements will never be exact and completely reliable but they can be useful as rough guidelines. In principle, when the private benefit-cost ratio is greater than one and the social ratio is lower than one, R&D projects should receive a low priority for public support. The higher the private ratio and the lower the social ratio the less public assistance is needed or justified

for a given project. Cases where the social ratio is higher than the private ratio should get priority.

The administration of the program should maintain an efficient system for auditing the results of all the projects it has supported. Most stages of the innovation sequence are risky and the government cannot expect that all R&D projects given public assistance will lead to successful innovations. However, the audit system will identify the firms that consistently fail to manage their R&D activities effectively. If these firms, after a trial period, cannot take the necessary steps to improve their efficiency and rate of success, they should lose public support.

The level of assistance should also be influenced by these guidelines and by the risk involved in the project. The government share of the cost should be on a declining scale of assistance, normally not exceeding 50 per cent and dropping to 25 per cent in some instances. The top figure should apply to all worthwhile research projects because they are usually more risky than development work. In general, public assistance should be proportionate to the degree of risk and the potential return to the economy.

In spite of the new techniques of quantitative evaluation that are being developed the strategy we suggest will always require a good deal of flair and qualitative judgment on the part of the administrators of the program. They will have to learn to work as partners with industry; at the same time they will have to make sure that government funds serve the public interest and are not wasted. It will not be easy to reconcile these two roles. The administrators will require special skill, experience, imagination, and prudence; they will have to be top people with a detailed knowledge of Canadian industry and great managerial ability, seconded by sound scientific and technological advisers. The selection of these people will be a key element in the success of this venture. The integration of all the present programs into one multi-purpose program will no doubt make it easier to recruit the right people.

It is impossible now to estimate the level of government expenditures that direct financial assistance will require. It will depend on the volume of in-house R&D the government is willing to transfer to industry through contractual arrangements, and on the number and kind of requests from industry. Only a trial and error approach to budget-making will work, at least during the next few years. We are sure, however, that it will take a substantial increase in government outlays to meet the proposed target for industrial R&D by 1980. We are equally convinced that these increased expenditures will represent a profitable long-term investment for the Canadian people if the strategy we have proposed is implemented.

2. *Industrial design*

Good industrial design is often important to the success of a new or improved product.

The Committee questioned an expert on architecture and industrial design, Mr. John Parkin, about the Scandinavian countries' success in designing articles for domestic use. Mr. Parkin pointed out that this achievement reflected a long history of concern with excellence and integrity of craftsmanship. In other words, the design reflected the culture and outlook of the Scandinavian people. The evidence presented to the Committee indicated that Canada was not successful in producing either designers or environments in which designers could work.

It appeared, too, that Canadian industry was not much interested in employing industrial designers. The Committee is therefore pleased to note the initiative taken by the Department of Industry, Trade and Commerce in giving companies the financial incentive under its Industrial Design Assistance Program (IDAP) to employ this type of skill.

Successful innovations are not always based on low cost. In developing a Canadian approach to industrial design, it is worth noting that in Scandinavia, this development depended not only on cultural outlook but, as in everything, on leadership—the leadership of skillful designers and the influence they had on younger people with ability. Denmark, for example, was not always distinguished by its performance in this area. Although there were strong roots in rural handicrafts, the machine age in Denmark, as in most other countries, led to the production of poor quality household goods. Then came the design breakthrough in the 1920s. An architect, designer, and propagandist for the arts of those days, Poul Henningsen, called for a democratic revolution. He wrote:

> Dear craftsmen friends! How can you expect us to go on respecting you, while this swindle continues in the name of art, and while you ignore all your obligations to the modern world? We have no proper tumblers, plates, water sets, spoons, knives, or forks, while richer homes are flooded with trash and rubbish at fantastic prices! Think a little, and consider your obligations to make things for the delight of your fellowmen in their daily life! Throw away your artists' berets and bow ties and get into overalls. Down with artistic pretentiousness! Simply make things which are fit for use: that is enough to keep you busy, and you will sell vast quantities and make lots of money![5]

An observer of the Scandinavian scene, Donald Connery, notes that this is precisely what happened. Other designers and engineers joined Henningsen in the Danish design revolution and this caused an extensive and successful

interaction between engineers, designers, craftsmen, and industrialists.[6] In Scandinavia, now, the artist and the designer have learned to make meaningful contributions to the technological process of industrial production. In Finland, for example, one of the largest manufacturers of porcelain household goods has a studio in which artists and designers can work together and with the latest technological developments in materials and production processes.

There are a few emerging trends that should be taken into account in the development of an identifiably Canadian approach to industrial design.

The industrial designer is usually the member of the team who bridges the gap between the social attitudes and cultural outlook of those in the market for the product and those who develop it. It is apparent that the requirements of users and the skills of producers, to name only two elements, are changing rapidly. The product will have to follow.

The visionary engineer Buckminster Fuller claims that he refuses to buy anything he cannot fix himself. In taking this stand he is probably reacting against the growing difficulty of getting broken equipment repaired and the sense of waste people feel as nonfunctioning products litter their homes. This attitude will no doubt be reinforced in the future by the growing concern with pollution and conservation. The result may well be a consumer revolt against the throw-away concept, against products that cannot be maintained in use over a long period of time.

Another challenge for the industrial designer is the limited skills of producers and repairmen in the growing markets of the third world. As an example, a Netherlands electronics company found it necessary to completely re-design radios for production in Africa.

Thus the industrial designer of the future may well have to design products that last for a long time, are easily repaired, and do not seriously damage the environment when they have to be thrown away. It will not be easy to reconcile these different requirements. But the Committee heard little evidence that the consumer goods industries were now putting more emphasis on industrial design to meet this kind of problem.

The Committee hopes that the Department of Industry, Trade and Commerce, which has already begun to give some support to industrial design, will note such trends and draw them to the attention of industry and design schools, and further encourage and assist the development of a new approach to design in Canada.

Similar considerations apply to those other designers of man's artificial environment, the architects. The recent Nobel laureate, Dennis Gabor, is one of several scientists who have pointed to the necessity for a fusion of art and technology. Gabor pays particular attention to the effect of technological

development on the city: "In less than a hundred years that gigantic steel-concrete-glass rabbit-warren stretching almost continuously from London to Peking, which the Greek architect C. A. Doxiadis has called *Ecumenopolis*", will prove that "technological civilization will then have led itself *ad absurdum*".[7] Gabor says the main responsibility for bringing "art" into the cities will be the architects'. Indeed, if future cities are not to be purely a reflection of the economics of technological possibilities, industrial designers and architects must play an important role in the decision-making process. In encouraging an emphasis on good design, the Department of Industry, Trade and Commerce should not confine its attentions to industry. It will have also to give further support to some industrial design training centres across Canada to enable them to organize professional interaction at the teaching level and prepare an adequate supply of first-class industrial designers. Otherwise industry may become more conscious of its weakness in this area but fail to find the skilled people to correct it.

3. *New assistance programs*

It should not be forgotten that the purpose of industrial R&D is to produce successful market-oriented innovations. The actual launching of the innovation is also usually less risky but more expensive than R&D operations. But government support for this last phase of the innovation process has to date been almost non-existent.

The kind of public support these activities need is quite different from what is required by R&D operations. The main problem is the shortage of capital and good management advice. The Committee thinks two new programs should be initiated by the government to plug these gaps.

The first is a special loan scheme with lower interest rates. Such a program has been quite successful in Japan. It should be designed for small and medium-sized firms that find it difficult or impossible to find venture or working capital on reasonable terms. This program should also include guaranteed loans.

The second is a special equity capital fund for the same general purpose, chiefly for new technology-based enterprises. The United Kingdom and Sweden have set up such public funds to compensate for the reluctance of private financial institutions to provide venture capital. The Canada Development Corporation will be fully occupied in preventing undesirable take-overs and in participating in the mergers that will become necessary for the conversion of the secondary manufacturing sector. The financing of technological

innovations is a highly specialized operation. Even where private venture capital companies exist, as in Sweden, it has been found that a public fund can be complementary to these firms, work in close co-operation with them, and, by sharing the risk, induce them to be more enterprising and extend their operations. The Committee has found that the private financial sector is particularly weak in Canada and that a public fund might not only fill a gap but help existing companies to become more dynamic and progressive.

These two programs serve the same purpose and are designed to assist the same kind of activities. For these reasons, they should be administered by a single agency. This new institution should develop a good management service to provide advice and guidance to the firms it assists. Inventors and innovators who want to launch an enterprise to exploit their ideas often have more creative imagination than managerial ability and realism.

This proposed institution should co-operate with the administration in charge of the R&D grants program and with the industrial research institutes in universities. The close ties the new organization will have to maintain with government industrial laboratories, the Canada Development Corporation, and with the industrial and financial community, as well as the financial means at its disposal, will enable it to fulfil an important role in launching successful innovations.

The Committee recommends, therefore:

1. That all existing specific grants designed to encourage R&D activities in industry be integrated into one multi-purpose program, and be administered by the Department of Industry, Trade and Commerce in the light of the broad guidelines proposed for the determination and management of these subsidies; and

2. That a lending and investing institution called the Canadian Innovation Bank (CIB) be created to support in co-operation with private venture capital companies the activities involved with the launching of technological innovations, especially in new or existing small and medium-sized firms, to provide managerial services to these enterprises and to be responsible to the Department of Industry, Trade and Commerce.

GOVERNMENT SERVICES

A variety of government services should be offered to industry to sustain its innovative capacity.

1. *Government intramural industrial R&D*

The ideal location for industrial R&D is in industry itself, because this is where technological innovations in most cases have to be introduced. However, there are two areas where government has to intervene as an R&D performer to serve the needs of Canadian industry and the national economy as a whole.

Certain industries like agriculture and fisheries and traditional industries in the Canadian North are characterized by a large number of relatively small firms which cannot usually sustain R&D activities on their own. There are sectors like forest and water resources, wildlife, weather conditions, and oceanography, where several industries and a substantial public interest are involved and where it is not desirable to rely solely on private initiative. This is one area where government has to take the main responsibility for financing industrial R&D programs.

Industries with fewer and larger firms still cannot carry out all their R&D requirements efficiently. Many firms spend relatively little of their time on testing for example, but the facilities required are extensive and expensive. This is typically the situation of mining and the secondary and service industries, which are quite capable of performing R&D activities themselves but need government research services in specific fields. In this area, however, the government merely has a residual responsibility and its role should be passive rather than active. It should be expected to complement the R&D effort performed by the private sector and to respond to specific needs.

We do not intend to review government's industrial R&D programs in detail. It would take several volumes and special technical studies, extending beyond our main assignment which is to deal with broad issues of science policy. The Science Council has published reports and studies on space, water and forest resources, earth sciences, agriculture, fisheries, and oceanography. Our Proceedings also contain a great mass of information on most of these specific programs and the role of the Canadian government.

What is now needed is a detailed appraisal by the Ministry for Science and Technology of the industrial R&D performed by the government and of the budget proposals and trends put forward by individual agencies for the 1970s. This systematic appraisal should be made in the light of studies made by the Science Council, analyses carried out in departments and agencies, and the broad targets and strategies proposed in this report. In addition we have some general observations on industrial R&D activities performed by the government that should also serve as guidelines.

Renewable resources and primary products

In the area of renewable resources and the primary products related to them, our comments apply in varying degrees to all mission-oriented government agencies involved in this sector.

First, there is a normal and general tendency toward self-sufficiency and over-expansion in these agencies. The Department of Agriculture provides a good illustration. In 1970-71, out of its total R&D budget of nearly $60 million, only $800,000, or 1.3 per cent was devoted to the funding of extramural activities.[8] The Committee suggests that the mission-oriented basic research performed by these agencies distracts them from their practical mission and that they should be obliged, as a general rule, to contract out this type of research, when they need it, either to the government basic research centres proposed in Chapter 14 or to universities. According to press reports this point has also been emphasized by Dr. P. D. McTaggart-Cowan, who is reported to have told a meeting of government scientists that "one or two [of Canada's university agriculture faculties] are second class and the rest grade downward to disaster areas and you did it". He suggested that the Canada Department of Agriculture had monopolized the research funds and starved university researchers. Dr. McTaggart-Cowan is also reported to have suggested that the forestry faculties at Canadian universities suffered from the same troubles and that not one of them was even second class.[9]

The natural inclination of these agencies to get away from their practical mission has led them to put their emphasis on research in the natural sciences rather than on the social sciences and on technological development work in engineering. The Department of Agriculture again provides a concrete illustration of this trend. For instance, in 1967-68 the Department employed 935 professionals (man-years) in research, 175 in development and 154 in scientific services. It spent $35 million in the natural sciences, but only $962,000 in engineering—a ratio of 36:1.[10] It is quite obvious, however, that new technology can play at least as important a role in improving the productivity of primary industries and the conservation of resources as new science can. We have only to think of what the tractor has meant for agriculture.

J. Harry Smith and Gilles Lessard, in their special study prepared for the Science Council on research in forestry, indicate several gaps in this area and claim that "The greatest potential for rewarding research in the forestry sector exists in the development of improved harvesting equipment and systems."[11] They add that "Forestry economics and fire science have suffered also from many years of neglect in Canada."[12]

More emphasis should be put on developing new instruments and specialized equipment to help agriculture, fisheries, forest harvesting and management, and water conservation. But since the technological innovations needed must be introduced by private firms, government mission-oriented agencies should contract out to industry the R&D activities required to develop the new products and processes rather than perform them in their own laboratories. Then, in most cases, the innovation process would be improved and the diffusion of the innovations would be more rapid.

We note that these agencies have put their emphasis on increasing yields and improving the output. These objectives are important, of course. It must be noted, though, that the increasing difficulties of some primary industries come mainly from over-production, marketing, trade obstacles, and substitutes produced by new technology. Almost two centuries ago, Antoine de Monthyon wrote:

> Il est un moyen simple de perfectionner la culture, c'est de donner aux denrées des débouchés.[13]

This is still true today. So research aimed at finding new uses for primary products at the manufacturing level may be of much greater help than efforts to increase their production. And yet mission-oriented public agencies have done, or supported in industry, relatively little research on new and more extensive uses for primary products. To the extent that they have shown an interest in this type of R&D, they have concentrated on intramural activities, as in the case of research on new or better uses for wood. A revolution is coming in food technology which may greatly favour some of our primary products and be fatal to others. But government mission-oriented agencies have shown relatively little interest in promoting innovations in this area.

The Committee concludes that government R&D programs undertaken to assist primary industries such as agriculture, fisheries, and forestry, should put more emphasis on manufactured goods that use primary products as raw materials. As the new emphasis is developed, the agencies should be obliged, when they submit their estimates for approval, to show why their programs should not be contracted out to industry.

The present situation is that industrial R&D performed by government agencies does not appear to have been very useful to the industries concerned. The furniture industry is a case in point. Table 23 shows that government agencies, technical schools and universities, and commercial laboratories have been its least useful sources of technical information. The Committee was concerned to learn of the case of Sea Pool Fisheries Limited, which started as a Canadian company at Clam Bay, Nova Scotia and in 1969 foresaw the pos-

sibility of producing four million pounds of fresh fish yearly. The Committee believes this firm received considerable scientific assistance from the Fisheries Research Board and other government agencies, and yet a paper written later by one of the company's staff reported that "... a general pessimism on the part of Federal agencies ... contributed to set-backs in the program to establish Sea Pool Fisheries as a new industry in the Maritimes."[14] (Some 93.5 per cent of this company is now owned by Marine International Corporation of Newark, New Jersey, which operates in many parts of the world.) Numerous comments to the Committee confirm that these illustrations are far from being exceptional.

Table 23—Usefulness of the sources of technical information to the furniture industry

	% of Replies	
	Rarely or never useful	Quite or extremely useful
Trade magazines	15	85
Scientific or professional journals	55	35
Material or equipment suppliers	7	93
Plant visits or advice from other companies	3	96
Trade associations or shows	21	79
Technical schools or universities	68	28
Government agencies	68	28
Engineering or technical consultants	42	49
Commercial laboratories	65	14

NOTE: Some companies in the survey did not provide views on all sources of information.
SOURCE: Woods Gordon and Company.

We suggest that the responsibility of government agencies for funding industrial R&D in this first area, that is, renewable resources and primary products related to them, now mainly located in the Department of Agriculture and the Department of the Environment, be limited to programs designed to conserve renewable resources, improve the yield, and increase the productivity of renewable resource industries. Within that limited context, they should contract out the mission-oriented basic research they need to the proposed National Research Academy or to universities. Their funding of R&D activities should be concentrated on development work leading to innovations. To the extent that their goal can be best attained by the development of new products, new equipment, and new industrial processes, they

should contract out this work too, preferably to private industry or to the complex of government industrial laboratories that we describe later. These agencies would not be responsible for R&D of manufactured products such as food technology or forest products. This would mean, for instance, that the forest products laboratories would be moved from the Department of the Environment and become part of the new complex to be referred to.

It may be that some of the existing programs should be abandoned or at least receive a lower priority. There may also be gaps to be filled. Only a detailed review of existing programs and future needs will tell if the R&D budget of these government agencies should be increased or reduced. We are inclined to think a significant reduction could be effected. But whatever the conclusion of the review, we are convinced that if our suggestions are followed, these agencies will have quite different priorities, that they will perform less R&D themselves, and that a more substantial portion of their R&D budget will go to universities and, especially, private industry in the form of contracts.

Manufacturing and non-renewable resource industries

In this second major area of industrial R&D, the government involvement in funding and performance should be complementary and residual compared with the effort made by secondary and service industries, power utilities, and the mining industry, including natural gas and petroleum.

These industries should be capable of carrying out extensive R&D on their own. But even here the Canadian government is now maintaining large industrial laboratories, located mainly in the National Research Council, the Department of Energy, Mines and Resources, Atomic Energy of Canada Limited, and the Defence Research Board. In Volume 1 we described historical origins of this situation and the philosophy that brought it about. This trend seems to prevail. For example, the Committee wonders whether locating the overall project management and design function for the research satellite program in the Department of Communications is not just another illustration of the reluctance of government agencies to contract out to industry. In 1971-72, the department will spend $12.5 million on intramural R&D activities but has provided only $4 million for R&D to be performed by industry. Mr. William J. Cheesman, former president of Canadian Westinghouse Company Limited, exposed this situation when he appeared before the Committee:

> The argument that is put forward for keeping those projects in the government laboratories is that only the government laboratories have the class, kind and quality of manpower to undertake these projects. The fallacy as we

> see it in that, of course, is that industry will never have the class, kind and quality of manpower required to undertake such projects until we have the projects to perform.[15]

On the basis of the evidence presented to the Committee, we have three general observations to make; they do not apply to all projects and agencies to the same degree but are fundamentally a valid description of the existing overall situation.

The government's industrial R&D effort in this second area is greatly over-expanded. In several sectors its agencies play the major role and have become substitutes for private laboratories, instead of complementing and supporting them. They continue to be animated by the old spirit of the early 1920s which was that they had to assume the main responsibility for R&D performance and that industry would innovate, merely by applying their findings. They have tried to become self-sufficient and to develop programs on as many fronts as possible to meet their respective missions the better. The natural inclination of institutions to expand has reinforced this trend.

In view of this prevailing philosophy, it has not been unusual for most of these government agencies to formulate and develop their R&D programs in isolation and to give them the orientation they thought best. The emphasis has been on basic and applied research rather than development. Government industrial laboratories have been administered as if they were basic research organizations. They have not been given specific missions and the selection of projects has been left largely to the initiative of individual research workers who have had practically no contact with industry and little knowledge of its real needs. These government agencies, which should have been conceived essentially as suppliers of services to industry, are in the position of deciding by themselves what kind of services they will offer: supply is in the position of creating its own demand. When such situations arise, awkward results can be expected. This point was illustrated in the Netherlands where a government laboratory went through great pains to develop a new technological device only to find that the country lacked the industrial capability to exploit the invention. In the end the invention had to be sold to a foreign company. Doubtless a number of similar experiences have occurred in Canadian government laboratories.

As long as there is little consultation with industry on the selection and formulation of programs, and the emphasis is on research rather than on development, R&D activities cannot be well adapted to industrial needs. A gap has developed between the results of research and the development of successful innovations. In addition, there is no effective means of transferring these results to industry. Often government agencies and private laboratories

do not know what the other sector is really doing. Two solitudes have grown up where continuing liaison and complementary relationships should be the rule.

The main sense of these generalizations was presented to the Committee in a highly critical tone by all segments of private industry (*see Chapter 9, Volume 1*). Of course, industry's views may well be biased. Some Canadian scientists, like Dr. A. E. Douglas of NRC, have interpreted conditions differently and have strongly criticized industry for its lack of innovative spirit and for not having used the results of R&D performed by government laboratories as it should. In June 1969 Dr. Douglas said, for instance:

> A second area of frustration and disappointment is in finding means of the transferring of the concepts and discoveries of our laboratories into Canadian industry. It has been claimed that our university and government scientists live in ivory towers where they shield themselves from the industrial world. These towers are not of ivory but of grey stone; they are prison walls, not of his own making. Show me such a physicist who has tried to have his invention developed by Canadian industry and I will show you a man with ulcers. At no time is the development of a new product easy, but in Canada, in physics, the difficulties are tremendous. This is not some vague general problem which we must discuss in a philosophical way, it is one which can be seen in our laboratory every day. While we are being called upon to give a better account of the means through which our laboratories will benefit Canadian industry, we find that the paths by which this benefit can be extended are very limited.[16]

Nor did Dr. J. L. Gray, president of AECL, express much confidence in industry as an effective R&D performer when he appeared before the Committee:

> . . . everybody is saying we must get all applied R and D into industry. But that is not easy. It is not easy to do research or development in Canadian industry. We put $6 million or $7 million worth of work into Canadian industry, and we have done this for 10 or 15 years, and we are working with our best Canadian companies, and it is hard work to get good results out of Canadian industry.[17]

However, Mr. W. J. Cheesman had this to say about AECL:

> We have a more recent example of one government laboratory that saw a large increase in its work-load and was exhorted by many to contract this work out to industry. Again the traditional observation was made that industry does not have the engineers and scientists who can perform this work. However, it is interesting to observe that the same government laboratory within two years was able to find the people to grow from 200 to approximately 800 within its own walls.[18]

These statements show the animosity and distrust that have grown over the years between two sectors that should have maintained close liaison and co-operation. The Committee is convinced that this situation must be radically changed. The only sensible policy in the long term is to develop the innovative capacity of industry where it does not exist and to use it as much as possible when it has been developed. This strategy offers the best guarantee that the direct results of R&D will be commercially utilized and that valuable "fall-out" will be recognized and exploited.

Up to now, government-operated industrial laboratories have been most reluctant to share their R&D activities with industry on a contractual basis. The only important exception has been in defence, where agencies were forced by a special government directive in the early 1950s to transfer some of their projects to industry. Mr. Cheesman cited a specific case to the Committee:

> A survey was done by a team back about 1950, which came back here to Ottawa with the report that the Canadian electrical and electronics industry did not have a research and development capability sufficient to handle the projects which were then under way in government laboratories. . . . by edict these projects were put out into industry. Industry recruited the scientists and engineers and built up the electronic industry. . . .[19]

Government edicts since then have been less frequent and less effective. In recent years, the level has remained fairly stable. Table 24 shows government payments for R&D performed by industry since 1966-67, when the tax incentive of 1962 was abandoned. If we exclude the loans made to Hydro-Québec and assume that all other payments, except the grants programs offered by NRC and the Department of Industry, Trade and Commerce, were made in the form of R&D contracts, we find that they amounted to $54 million in 1966-67 and $46.5 million in 1971-72. There was a substantial decline in the sectors of National Defence and AECL and an increase in the field of Communications during the five years. This amount of $46.5 million is small compared with the estimate of about $300 million provided in 1971-72 for government intramural R&D activities, of which a substantial portion is devoted to industrial purposes. Clearly there is room to strengthen R&D performance by private industry and a good prospect of spin-off effects on the industrial innovative process.

To support this suggestion of a new approach to the performance of industrial R&D, we note that scientists and engineers within government laboratories and industry usually have different motivations and standards of behaviour. David C. McClelland of Harvard University is one who has noted the difference, which he attributes mainly to environment. Entre-

Table 24—Payments to Canadian Industry for Research and Experimental Development, 1966-67 to 1971-72
(Millions of dollars)

Department or Agency	1966–67	1967–68	1968–69	1969–70	1970–71p	1971–72p
A.E.C.B.	—	—	—	—	0.1	0.1
A.E.C.L.	28.5	27.2	35.8	33.3	30.6	22.1
Canadian Transport Commission	—	—	—	—	0.4	0.4
Communications	—	—	3.3	2.7	3.9	4.0
Energy, Mines and Resources	—	—	0.4	0.1	11.3[1]	3.4[1]
Environment	—	—	—	0.7	1.2	1.5
Fisheries and Forestry	0.8	0.3	0.1	—	—	—
Industry, Trade and Commerce	25.8	31.3	45.7	52.1	67.0	82.6
National Defence	24.1	19.7	17.0	13.7	13.3	16.8
N.R.C.	4.2	5.0	5.8	6.2	7.4	8.6
Public Works	—	—	—	0.1	0.1	0.1
Transport—Other	0.4	0.9	0.6	0.7	0.2	0.4
Other	0.1	0.1	0.2	0.1	0.1	0.1
Total	83.9	84.5	108.9	109.7	135.6	140.1
Payments to educational and non-profit institutions	56.1	82.2	108.9	113.3	118.3	127.8

SOURCE: Statistics Canada, August 1971; Cat. No. 7013–501; Advanced Statement No. 1; Table 9.
p = preliminary.
[1]Loans to Hydro-Québec of $11 million in 1970-71 and of $2.5 million in 1971–72 are included.

preneurial R&D people in industry, he finds, can be ardent champions of their ideas rather than objective observers of the scene. They take risks and expect to be rewarded for successes. On the other hand, McClelland points out that "obviously achievement is only one of government's concerns and often it is of secondary importance . . . ". And he goes on:

> Bureaucrats must be impartial, disinterested; they must treat all applicants for service universalistically, without regard to race, creed or color; they must not get personally involved with the clients they serve. . . . this leads to an excessive concern with correct procedures as contrasted with the excellence of results. . . . Researchers living on government money tend also to learn in time that it is more important to do the right (i.e., the defensible) thing than it is to get results in the same sense that a businessman means "results" when he is thinking of profitability. The source of quality control again is different—not results exclusively, but doing the "right" thing in the most general sense.[20]

The Committee noted that in many of the briefs presented by government departments or agencies, there were lists of what these organizations called "major projects". In many cases there was no more than half a QSE per

"major program", however. In other words, some government laboratories claimed to have "major programs" intended to benefit industry, but manned them with a research staff whose size bore no relation to the supposed dimension of the R&D work. During our questioning of the head of a government laboratory, this point was made and the witness admitted that many of the projects were quite small. We were surprised that an agency would present a long list of what it called "major projects" and then confess that some were in fact small jobs taking a few days.

The differences in behaviour standards imposed by government and industry indicate why the government sector is naturally more inimical to inventions and innovations aimed at the private market than is industry. These provide another reason for transferring industrial R&D programs out of government laboratories and into the private sector.

In conclusion, the Committee believes that general guidelines should be developed to determine the role of existing government laboratories in this second broad area of industrial R&D.

It should be made absolutely clear that the *raison d'être* of these public agencies and their in-house programs is to assist industry, not replace it. The first task of existing laboratories should be to help create R&D capacity in industry, where it does not exist, and use it to the utmost to carry out their own industrial R&D programs through contractual arrangements. In the future, when the government feels that it has to sponsor new industrial R&D programs, it should carefully review the situation with industry before initiating in-house activities of its own and then do so only under exceptional circumstances—in most cases, on a temporary basis until private laboratories are ready to pick them up.

The current programs of government laboratories related to secondary and non-renewable resource industries should also be systematically reviewed to see if they should be abandoned, if the facilities and personnel supporting them should be given a new mission more important to industry or the community at large, and if the work could be carried out with greater benefit by industry or universities.

The Committee has the impression that some of the laboratories operated by the Defence Research Board, for example, have accomplished their original missions and should be given new assignments or transformed into joint university-industry ventures. We think now is probably the time to transfer the facilities operated at Whiteshell by AECL to a group of universities since it has been asserted that this laboratory is now being used mainly for materials sciences. Several countries have substantially reduced the number of R&D personnel in their atomic energy agencies or given them new missions. Power

utilities should assume a more active role in R&D on nuclear energy; Hydro-Québec has already expressed its interest in doing so. (The power utilities will have to operate these nuclear plants and integrate them into their systems.)

While these activities are being abandoned or assigned to industry, universities, or the proposed National Research Academy, plans should be made to bring the government's industrial laboratories together under the authority of the Department of Industry, Trade and Commerce. We suggest that the date for this transfer should be no later than March 31, 1973. Whatever R&D work they retain should be under continuous review with representatives of the industries concerned to make sure it continues to meet changing industrial requirements. As a result, the transfer of knowledge to industry would become more direct and effective and the programs of these laboratories could be more easily adjusted to an overall industrial and technological strategy.

To attain these objectives, interested industries should be strongly represented on the board or advisory committees of these agencies. As these changes would be made specifically for the benefit of industry, the Committee suggests that industry should make a growing contribution to the financing of these facilities. Among other things it would guarantee industry's interest in the laboratories.

In order to ensure that these principles are followed, the Committee believes it is essential to impose a financial and manpower limit on the continuing growth of government laboratory and departmental industrially-oriented R&D activities. This limit should be imposed from the 1973-74 fiscal year onward, which will give time for industry and the laboratories and departments concerned to transfer programs to industry and redirect in-house programs in line with the strategy proposed by the Committee. Growth in federal expenditures above this limit should either be used to increase the financing available through the direct assistance programs, or to contract out departmental R&D to industry.

The Committee recommends, therefore:

1. That a detailed and continuing review be undertaken by the Ministry for Science and Technology of current and future industrial R&D programs of government departments and agencies involved with renewable resources and related primary industries such as agriculture and fisheries, and that the objectives of such a review be to make sure that these agencies do not get involved in R&D activities on manufactured goods based on primary products, abandon or reduce certain programs which have a

low Canadian priority, and contract out their mission-oriented basic research to universities or to the National Research Academy, and as much as possible of their development work to industry;

2. That the Ministry for Science and Technology undertake a review, with the same objectives, of industrial R&D programs in laboratories operated by government departments and agencies for secondary and service industries as well as for mining and power utilities;

3. That on March 31, 1973, these latter government laboratories be brought together in a new Crown company called the Canadian Industrial Laboratories Corporation (CILC) with a strong industrial representation on its board and committees and a growing industrial contribution to its financing and to be responsible to the Department of Industry, Trade and Commerce; and

4. That pending the results of the proposed detailed review, a financial and manpower limit be imposed on intramural industrially-oriented R&D activities, commencing in fiscal year 1973-74.

2. *Technology transfer, information, and forecasting*

One of the most valuable services the government can render industry is to help gather and distribute technological information and forecasts. To develop a sound innovative strategy, private firms and industries must detect technological trends at home and abroad as early as possible. Dr. Chisholm maintains that the best way of viewing a laboratory is not as a generator of information but as a processor of information:

> The generation idea is not even self consistent. The biggest lab in Canada is one tenth the size of its U.S. counterpart and perhaps a few percent of the world effort. Thus if it is as good as the rest we might expect it to generate a few percent of the useful new ideas. If it can couple in ideas, acting as an information coupler or pump, it can, like a heat pump, have an efficiency far greater than 100%.[21]

It has been observed that most technological innovations are visible long before they are operationally applied. They can be anticipated or detected more easily as technological information becomes more readily available and their potential impact on any firm or industry can be assessed before their use becomes widespread. Literature on technological forecasting is growing rapidly. Look-out institutions specializing in this field make their findings available to subscribers.

A firm wishing to take full advantage of new technological opportunities, to protect itself from negative effects, and to determine what new products or processes it should try to develop must have a good technological monitoring service. According to James R. Bright, professor of technology management at the Graduate School of Business, University of Texas, monitoring includes four activities:

> 1. Searching the environment for signals that may be forerunners of significant technological change.
> 2. Identifying the possible consequences (assuming that these signals are not false and the trends that they suggest persist).
> 3. Choosing the parameters, policies, events, and decisions that should be observed and followed to verify the true speed and direction of technology and the effects of employing it.
> 4. Presenting the data from the foregoing steps in a timely and appropriate manner for management's use in decisions about the organization's reaction. . . .
>
> The corporate management that ignores the warnings and opportunities in signals of impending technological change is trusting to luck, intuition, and the assumption that it will still have adequate freedom of action.[22]

A good technological monitoring service is of crucial importance for an individual firm or industry. Monitoring on a large scale and in the most important industrial countries of the world has made a major contribution to Japan's technological success.

It is usually too expensive for smaller firms to develop their own monitoring system, but the work is not of such a secret nature that it has to be kept exclusive. It can be pooled efficiently and satisfactorily. Each Canadian industry should consider whether an industry-wide monitoring system could perform a useful function for individual firms.

But these private systems must be complemented by a public monitoring service, with adequate representation abroad. This service would be responsible for stimulating the creation of specialized systems in the public as well as in the private sectors and for serving as a national clearing-house. The intention would be to develop a monitoring network on new technological developments occurring in the world. This clearing-house and national network should also lead to a better selection of R&D programs in government agencies, make it easier to determine science policy, and provide an overall assessment of the potential opportunities and dangers that new technologies can have on the quality of life in Canada.

Experience shows that inventions capable of leading to important innovations are frequently made and developed outside the industry concerned.

Firms do not always perceive scientific or technological developments that present new threats or opportunities because of their commitment to traditional attitudes. Some spectacular examples are well known: xerography, the transistor, instant photography, and jet engines among them. A public monitoring service should scan the world for major technical and scientific events and query the appropriate Canadian industrial sectors for their reactions. This is probably what Richard R. Nelson had in mind when he said:

> The other component of a national technological policy is skillful identification of the situations and activities where the market does not work well. Here in addition to special social values which are associated with certain products, policy should be alert to the breakdown of market incentives for exploratory technological efforts which have long-run implications.[28]

The service should also review all research activities in university and government laboratories and, in co-operation with industry, identify the programs that present a real opportunity for Canada. This review should also cover all patents registered in the country.

In Chapter 13, the Committee recommended the establishment of a national R&D inventory and audit service of R&D programs and projects being supported by public funds, and suggested the need for an overall Scientific and Technical Information System. We do not believe that this system should be completely centralized either in its gathering or its distributing operations. The National Science Library should be operated by the National Research Academy that we proposed in Chapter 14. Information on the industrial innovative process, inventions, patents and innovations and the responsibility for encouraging its effective transfer should be the main responsibility of the Department of Industry, Trade and Commerce, in collaboration with the provincial research councils. (The Committee will deal at greater length with the relationship that should exist between these councils and federal departments and agencies in a subsequent volume.) Canadian Patents and Development Limited should be integrated into the Department of Industry, Trade and Commerce technology transfer system. The private communication industry should be asked to contribute as much as it effectively can to the undertaking. Since this national service cannot be completely centralized, it will need integration and leadership if it is to serve its purpose.

The Committee, therefore, recommends that:

1. The Ministry of State for Science and Technology be given responsibility for initiating the creation of new scientific and technical information and transfer systems and technological forecasting services in co-operation

with the proposed National Research Academy and the Department of Industry, Trade and Commerce and in consultation with the communication industry;

2. The main operating responsibility for the collection, storage, and dissemination of scientific and technical documentation should be assigned to the proposed National Research Academy, and the operating responsibility for the collection, storage, and effective transfer of information and technological forecasts concerning the industrial innovative process should be assigned to the Department of Industry, Trade and Commerce, while enabling other government agencies to maintain their own systems according to their specific needs;

3. The Ministry of State for Science and Technology be responsible for the continuing review and evaluation and coordination of the various government agencies' scientific and technical information and technological forecasting activities; and

4. All these activities be arranged so as to encourage the development of a Canadian information and forecasting industry to which the two ministries named above should give high priority.

Given the overall interest of the ministry in all aspects of science policy, it seems to be the logical leader in the information area.

The Committee would like to cite only one out of many examples of where this central service could be useful. It is now widely recognized that the next major breakthrough in the field of nuclear power will be the fast breeder reactor, which will produce more fuel than it consumes once it is in full operation. Great Britain and the Soviet Union appear to be leading the way and are now in a race to start up the first prototype. Canada has not done any systematic work in this area but is vitally interested in its development.

Several questions arise. When the fast breeder becomes operational, which is expected in the late 1970s, what will its impact be on the short term and long term prospects of our uranium industry? Will it open up a market for the plutonium produced by the CANDU reactor developed by Canada, as AECL expects, or will the Americans be in a position to derive large quantities of this fuel from obsolete nuclear weapons that they have recently decided to dismantle? Will the fast breeder reactor be able to produce cheaper power than our CANDU system? Will the co-operative arrangement for the free exchange of technical information existing between Canada and Great Britain, which enabled the British to produce their SGHWR reactors largely on the basis of technology developed in Canada, apply in the opposite direc-

tion and give us free access to British technological information about fast breeders? It seems to the Committee that these are just the kind of questions that integrated technical information and co-ordinated technological forecasting services should be able to answer, or at least help answer.

3. *Supply of scientific and technological manpower*

If the targets proposed by the Committee are to be achieved, the industrial sector will need a rapidly growing number of QSEs trained to meet its requirements. We have recommended a special study to evaluate the number and quality of people needed in the 1970s. We hope that when the magnitude of the problem becomes known, universities with the support of provincial governments will prepare themselves to meet the situation and that students will not only avoid careers where surpluses already exist but will be less reluctant to seek jobs in industry.

The Canadian government can play a useful role by readjusting its scholarship and fellowship schemes to persuade students to get the kind of training industry will require. This should prove an effective way of inducing universities to adjust to the new demands.

Another aspect of manpower policy must be mentioned. It is almost impossible for a scientist or an engineer to spend all his life in the same laboratory and environment and still keep his intellectual curiosity, his mental alertness, his day-to-day enthusiasm and morale. It has been said that by the age of 40 most scientists have given their best to research and should seek another career. Isolation from the real world is probably at its worst in government research establishments, where the researcher has no special inducement to apply his scientific discovery or develop his invention, and in most cases is denied even the stimulant of teaching.

In Chapter 14 we suggested that scientists should be encouraged to transfer from the proposed centres of basic research to mission-oriented government agencies. This corresponds to the practice in large industrial firms' basic research laboratories. Research directors of several such companies told the Committee that they keep a watchful eye on their basic research laboratory to make sure researchers' progress corresponds not only with their success in basic research itself, but with their interest in being transferred. They could be transferred to other parts of the organization to learn new skills or take on other responsibilities.

But transfers within the government sector are not sufficient. Given the urgent need to reinforce industrial R&D in the private sector, the administration should make it easier for scientists and engineers to transfer tem-

porarily or permanently to industry. Present working conditions in the public sector tend to discourage such movements. One obstacle, it is said, is that pension rights are not portable. Lower salaries, especially in smaller businesses, can also be a hindrance. Most of the difficulties could be overcome. It would even be a good investment for the government to organize a system of free loans of research personnel to smaller firms. This would enable these enterprises to strengthen their R&D effort and provide an opportunity for government scientists and engineers to work in a new environment, face new challenges, and extend their career of useful service.

The importance of personal mobility in spreading technology and developing innovations cannot be overstressed. For example, Donald A. Schon, a student of the innovation process, points out that " . . . examples of significant technological change are mostly examples of outsiders moving in".[24] He argues that mobility of R&D personnel from one institution or sector to another constitutes our "principal sources of technological change in our society and have been so for at least the last fifty years. What we talk about as 'technological transfer' falls within this pattern". He goes so far as to say:

> I believe that movement of people, organizations, and institutions—not information—is the issue. "Information", "transfer" and "documentation" are merely luggage.[25]

Derek J. de Solla Price has also stressed the importance of mobility. He urges a larger continuous flow of people from government research payrolls back to the universities and, "most vitally, back to private industry". He adds that the noted Russian physicist, Peter Kapitza, has made a similar suggestion;

> [Kapitza] notes that there is far too much stability in the scientific establishment and that it would be generally helpful to fire people rather extensively so as to create more openings at the lower end. This means of course not any decrease in the number of scientists and technologists employed, but a large increase in mobility and consequently a considerable increase in the communication that is affected by people acting as containers of the research front tradition and state of the art in science and technology.[26]

The Committee recommends, therefore, that:

1. The Ministry of Science and Technology review all scholarship and pre-doctoral fellowship programs sponsored by the Canadian government in light of projected QSE requirements for the 1970s, mainly in the technological sectors, including social engineering and business management, and with the view of eliminating emerging surpluses in certain areas and scarcities in others; and

2. The ministry develop a program in co-operation with the Public Service Commission and the Treasury Board to facilitate the mobility of R&D personnel within the government and between universities, industry and public agencies, with special emphasis on transfers from government to industry.

CONCLUSION

The Committee has devoted a lot of attention to industrial R&D and market-oriented economic innovations because it feels that Canada is particularly weak in that area and that the filling of that gap should become a major national objective in the 1970s. We are deeply convinced that it is in the country's best long-term interests to make a substantial shift in Canadian growth objectives and strategies as quickly as possible. We are not alone in these concerns. The Economic Council of Canada's recent report, *Performance in Perspective,* ends on a similar note:

> The prospective entry of Britain into the Common Market once more raises the question of Canada's place in a world economy that is becoming increasingly dominated by groups of nations operating in large tariff-free areas of a hundred million or more consumers. Canada greatly needs the advantage of scale and specialization that access to such markets confers if she is to sustain a dynamic and vigorously growing secondary manufacturing sector. We believe this to be an essential component of an industrial strategy for Canada, especially in the light of the rapidly growing employment needs of the economy and the present heavily resource-oriented structure of our industry.[27]

This shift in emphasis will require a radical change of attitude from almost all segments of the population. Business management of secondary manufacturing and resource-based industries will have to forget the growth patterns of the past and learn how to live and expand with the delicate innovative process, which is a perpetual new beginning. Canadian workers, who always have been quite mobile, will have to adapt even more quickly to rapid technological change. Students, universities, and the scientific and engineering communities will have to change motivation and agree to participate more actively than in the past in the economic progress of their country.

Above all, public authorities and particularly the Canadian government will not only have to support the new industrial and technological strategy but also plan forward to maximize the benefits and minimize the negative effects of innovation. What we need, in fact, is a new National Policy, a technological strategy that combines science policy and industrial policy into

a new innovative synthesis. The Canadian government, in co-operation with the provinces of course, must not only substantially improve the public climate surrounding financing of the whole industrial innovative sequence but directly assist in it. It must also serve as a unifying force bringing the university, industry, and government sectors closer together. It has a good reason to become the driving force in this national venture: it has substantial stake in its success, through the tax system.

The new strategy will help to develop greater Canadian unity and identity. The old National Policy, launched in 1879, was divisive because it did not favour Canadians involved in the export trade. The strategy developed at the beginning of this century to encourage exports of raw materials and primary products was also divisive because it caused growing problems for the regions that relied most heavily on secondary manufacturing industries and that had few natural resources. In addition, it helped to make the Canadian economy a reproduction and an adjunct of the U.S. economy.

A new National Policy based on a high flow of innovation contains no inherent bias against any region, particularly if it is coupled with a realistic strategy for regional expansion. Moreover it is no longer merely responsive to foreign requirements. It must rest primarily on the Canadian innovative spirit and on initiatives taken in Canada to develop new applications of the principle of international comparative advantage. It would, therefore, provide Canadians with a great opportunity of regaining the lead in determining the long-term orientation of their own economy.

NOTES AND REFERENCES

1. Sir Alec Cairncross, "Government and Innovation", *op. cit.*, p. 502.
2. J. H. Hollomon and A. E. Harger, "America's Technological Dilemma", *Technology Review*, July 1971, pp. 31-40.
3. Donald A. Chisholm, "Thoughts on Innovation in Canada", *op. cit.*, p. 3.
4. OECD, *The Conditions . . .*, *op. cit.*, p. 64.
5. Donald S. Connery, *The Scandinavians*, Simon and Schuster, 1966, p. 174.
6. Ibid., p. 175.
7. Dennis Gabor, "Art and Leisure in the Age of Technology", contained in the *Social Context of Art*, edited by Jean Creedy, Tavistock Publications, London, 1970, p. 47.
8. *Two Blades of Grass: The Challenge Facing Agriculture*, Report No. 12 of the Science Council of Canada, Table 7, p. 32.
9. "Farm Faculties Second Class, Scientists Told", *The Globe and Mail*, Sept. 29, 1971.
10. *Two Blades of Grass . . .*, *op. cit.*, Tables 4 and 5, p. 31.
11. J. Harry G. Smith and Gilles Lessard, *Forest Resources Research in Canada*, Background Study for the Science Council of Canada, Special Study No. 14, May 1971, p. 165.
12. Ibid., p. 164.
13. Quoted by Michel Cepede, "Élaborer une stratégie alimentaire mondiale pour la prochaine décennie", *Le Monde diplomatique*, June 1970, p. 5.

14. Gary K. Gunstrom, "Sea Farming in the Maritimes", Sea Pool Fisheries Limited, Lake Charlotte, Nova Scotia, August 4, 1970, p. 4.
15. Senate Special Committee on Science Policy *Proceedings,* No. 68, June 19, 1969, p. 8113.
16. A. E. Douglas, paper presented at the Canadian Association of Physicists Meeting, Waterloo, Ontario, 24-26 June, 1969, p. 8.
17. *Proceedings, op. cit.,* No. 5, October 30 and 31, 1968, p. 676.
18. Ibid., No. 68, *op. cit.,* p. 8114.
19. Ibid., pp. 8113-8114.
20. David C. McClelland, "The Role of Achievement Orientation in the Transfer of Technology", in *Factors in the Transfer of Technology,* edited by W. H. Gruber and D. G. Marquis, the M.I.T. Press, 1969, pp. 75-76.
21. Donald A. Chisholm, "Thoughts on Innovation in Canada", *op. cit.,* pp. 5-6.
22. James R. Bright, "Evaluating signals of technological change", *Harvard Business Review,* January-February 1970, pp. 64 and 70.
23 "World Leadership and National Science Policy", *Minerva,* Vol IX, No. 3, July 1971.
24. Donald A. Schon, "Comments on Section I; Innovation: The Development and Utilization of Technology", *Factors in the Transfer of Technology, op. cit.,* p. 86.
25. Ibid., p. 25.
26. Derek J. de Solla Price, "The Structures of Publication in Science and Technology", in *Factors in the Transfer of Technology, op. cit.,* p. 103.
27. *Performance in Perspective 1971,* Economic Council of Canada, October 1971, pp. 56-57.

18

SUMMARY AND CONCLUSION

In this volume, after reviewing the background and framework of an overall science policy for Canada in the 1970s, the Committee has concentrated on "the first generation of science policy", centred around basic research and industrial R&D.

We have also paid more attention to planning and the study of the future. Nowhere, we suggest, is citizens' participation more important. If participatory democracy is emerging as a basic ingredient of our national life to-day, to-morrow it will have to be accompanied by a shared view of the future and commitment to plans for it—to "anticipatory democracy," that is. The quality of our life and the limitations to our future expectations will both be largely determined by the way Canadians and their institutions use science and technology. Responding to this need, the Committee proposes a committee on the future to serve as a national lookout institution, to develop forecasts and methodology and act as a research and advisory body. In addition we propose a commission on the future comprised of many private and public organizations, which would be encouraged to develop and share their own future planning.

These concepts apply equally to the Canadian R&D effort, which we maintain should be planned within medium-term and long-term perspectives. It is important for the national scientific and technological information network to be substantially improved. This country and its governments will not be able to formulate a realistic and coherent science policy without looking more systematically at the future and the international scene.

Turning to aggregate R&D expenditures, we propose 2.5 per cent of GNP as an overall target for 1980. It includes every part of R&D from basic

research up to the launching of an innovation. Some may argue that the target is too high; a few that it is too low. Others will even claim that the very idea of setting a target is meaningless and that a national budget for science, technology, and innovation should be determined by the multitude of daily micro-decisions taken within governments, universities, industries, and other private organizations.

Having looked carefully at the experience of other countries, the Committee rejects this unplanned approach. We are convinced that, without an overall target, it is practically impossible to formulate a balanced national R&D effort and a coherent overall science policy. Given Canada's obligation to contribute to the pool of international scientific knowledge through basic research and its interest in taking an active part in the international technological race, we also believe that the proposed target is reasonable. This does not mean, of course, that the target has to be achieved even if it involves inefficiency and waste: obviously only worthwhile projects should be undertaken and supported by public funds. But if Canadians cannot develop enough valuable projects to reach the target by 1980, that would be a cause for concern. If the nation were discovered to be as weak as that, the situation would have to be corrected at once, for otherwise we would not be able to meet international competition or satisfy our growing social needs.

The Committee hopes that the target, strategy, and priorities apportioned to basic research will be accepted. We propose that above an amount sufficient to maintain a broad scientific capability, the Canadian effort in this area, so far as it is supported by public funds, should be considered as an international obligation and be more or less proportionate to that of other industrially advanced countries. We suggest a strategy for developing excellence at the post-doctoral level and we think it necessary for curiosity-oriented basic research to remain completely free from outside interference once excellence, appraised by peers, has been achieved and within broad guidelines for social merit. We recommend that the Canadian government set up a Canadian research board with three foundations to be exclusively responsible for the financial support of curiosity-oriented basic research done in universities and similar institutions, in the physical sciences, the life sciences, and the social sciences and humanities. While the criterion of excellence should be preserved, we feel that in the 1970s special attention should be given to the social sciences, the humanities, and the life sciences.

To complement the role of universities and similar institutions and meet the requirements of mission-oriented government agencies, we propose that the Canadian government create a national research academy, whose main purpose would be to carry out mission-oriented basic research. The academy

would be composed of three institutes, one each for the physical sciences, the life sciences, and the social sciences. A substantial portion of the academy's activities would be in contractual research for other government agencies or industry. The institutes would also be expected to contract out some of their work to universities.

This integration of government intramural basic research would strengthen the quality of the work, facilitate a multi-disciplinary effort, and enable other government agencies to concentrate their R&D activities on the more practical side of their missions. On the other hand, it would be difficult for the academy to become an ivory tower. Through frequent exchanges of staff and contractual arrangements, it would have to maintain close liaison with universities, industry, and other government establishments.

We consider basic research a noble activity and feel that pure scientists should work in an atmosphere of complete freedom. Our insistence on the criterion of excellence would probably mean that fewer of them would be supported by public funds but those who did qualify for grants would be more generously supported and less closely supervised.

The Committee has devoted three chapters to industrial R&D leading to technological innovation in the private sector. We have detected a great weakness in this area, which explains the fact that the Canadian economy has never been highly innovative. We believe that the old policy of high tariff protection should not be restored and that the national strategy followed since the beginning of the present century, which relies mainly on the rapid exploitation of natural resources and on exports of primary products, is increasingly unwise in the context of current and future world supplies and requirements. Moreover Canadian long-term economic growth cannot be based on services as prime movers, although the complementary investment and employment generated in this sector by expansion in manufacturing is great.

The Committee has come to the conclusion, on the basis of the intensified international technological race and emerging world trade patterns, that in this decade Canada's growth strategy must rely mainly on a high and sustained flow of technological innovations introduced by the secondary manufacturing sector of the economy. This is a new and formidable challenge, which we have described as the Canadian innovation operation. It will not succeed unless it becomes a major national objective involving the active participation of all Canadians. It will require fundamental changes in our national life and our traditional outlook and attitudes.

As it stands now the Canadian private environment is rather unconducive to industrial innovations. To make it favourable, the secondary manufacturing

sector will have to undergo a major conversion. Most industries are composed of too many small firms and of businesses that have not rationalized their operations and developed maximum efficiency. As a result, their R&D effort is usually weak and inefficient. In the United States in particular, research intensity has been found to be an important cause of economic growth, increased sales and profitability. In Canada, private industry seems to see an inverse relationship and to wait for rising sales and profitability before increasing its R&D activities. This vicious circle must be broken.

The substantial transformation of secondary industry is partly aimed at building up an innovative capacity. It gains urgency from the fact that it is a preliminary to the proposed Canadian innovation operation. But even though it is only a prerequisite, it will take complex technical studies, detailed plans, and close co-operation between firms in various industries and between labour, management, and governments to implement these plans with the minimum of dislocation. As preparation the Committee proposes the setting up of a series of task forces of industrial and labour representatives in each industry, each working with the assistance of a chairman and small secretariat appointed by the Minister of Industry, Trade and Commerce. We see these task forces primarily as an exercise in participatory democracy: the detailed conversion plans must be prepared by insiders with an intimate knowledge of the difficulties of their industries, not imposed from outside by governments which lack the specific experience needed to develop practical solutions.

As this conversion proceeds and secondary manufacturing builds up its innovative capacity, as many firms as possible, including those in resource-based and primary manufacturing industries, will have to examine their innovative and R&D performance and make plans to improve it, in order to economize resources, utilize wastes more efficiently, find new ways of reducing costs, develop new uses for products, and process resources some stages further in Canada.

To achieve these goals and make the Canadian economy more innovative will require new and more aggressive attitudes from management, the active co-operation of unions, and probably a new approach to labour relations. Universities will have to reconsider their role as training institutions and co-operate with business in forecasting the number and kind of qualified scientists and engineers industry will need. The Canadian financial community must learn to take risks and understand the innovative process better. It must be prepared to finance innovations. Industry will need more and better qualified industrial R&D managers to help define innovation strategy and see that industrial laboratories apply it.

All these ingredients will be necessary to make the Canadian private climate capable of sustaining a high flow of successful industrial innovations. It is obvious, however, that the private sector alone cannot make the Canadian innovation operation the success it must be. All levels of government in Canada must do all they can to support and complement industry's effort.

It is beyond the Committee's prerogative to make specific recommendations to provincial governments, though in a subsequent volume we will have something to say about relations between the federal government and the provinces in the general area of science policy. We have found that the environment created by the Canadian government is not as favourable to industrial innovation as it should be. In proposing an aggressive new industrial policy we note that the major areas of federal policy have a significant though indirect effect on the environment for innovation. Decisions on trade and tariffs, taxation, the money supply, foreign ownership and control, competition, patents, government procurement, standards, labour relations and manpower, regional expansion, and pollution abatement are often taken without adequate consideration of their impact on the industrial innovative process. We conclude that if the present decision-making procedures are maintained, the government will not be able to carry out a coherent technological strategy and the major objective of the new National Policy will not be attained.

The Committee recognizes that the government departments and agencies involved must pursue their main missions. We propose, however, that in the process of formulating their policies, they should get the advice of science policy experts and that their proposals should be reviewed by a strong interdepartmental committee before final decisions are taken. This should help to improve the innovative climate and we hope that the departments and agencies concerned would not regard the reviews as an undue interference.

An essential ingredient of the new strategy is the direct assistance the government can offer, in services and fiscal incentives, to promote industrial R&D and innovations.

We observe that the existing government scientific information network could be substantially improved, relocated, and developed into a useful technological information and forecasting service for industry. Scholarship and pre-doctoral fellowship programs should be better adjusted to industrial requirements. It should be easier for R&D personnel to move between government and industry. Industrial design should be more systematically encouraged.

It is widely recognized that industrial R&D activities in government laboratories are over-expanded, too dispersed, and often misdirected. We propose that government's industrial R&D projects should be closely examined and

contracted out to universities or industry whenever possible. Meanwhile the number of government personnel engaged in intramural industrial R&D should be kept at the present level.

We specifically suggest that the government agencies involved with renewable resources and related primary industries, such as agriculture, fisheries, and forestry, should not undertake R&D programs on manufactured goods based on primary products. Laboratories doing R&D for secondary and tertiary industries, mining, and power utilities should be integrated into a single complex, responsible to the Department of Industry, Trade and Commerce and increasingly financed by contributions and contracts from private industry. These proposals would ensure that less industrial R&D is performed by the government and more by industry. They would also mean that the remaining intramural industrial R&D performed by public agencies would meet the real needs of industry more exactly.

As for financial assistance, it should be available in various forms for all phases of the innovative process. Within broad guidelines giving first priority to secondary manufacturing and the further processing of raw materials in Canada, the approach should be basically non-selective, although the government should not hesitate to ask firms in industries where innovative performance is poor how their situation could be improved. The Committee has come to the conclusion that all existing fiscal grants should be integrated into a single, multi-purpose program to be administered by the Department of Industry, Trade and Commerce. In addition, a special agency should be created to provide loans, equity capital, and management advice to help small and medium-size firms launch technological innovations.

That, in capsule form, is the message of this volume; these are its proposals. We hope its main theme comes across loud and clear: the re-orientation of the national effort in basic research and in industrial R&D and innovations should be an exercise in participatory democracy.

We want the pure scientists to remain free. We hope they will accept their social responsibilities and, through an effective peer system, apply to themselves the criterion of international excellence, recognizing that their main challenge is to expand the world's pool of scientific knowledge.

Our message to industry is basically the same: business management bears the primary responsibility for building up innovative capacity and using it as effectively as it can. As in basic research, the objective should be excellence too, but in industry it will be achieved through a high flow of innovations that put Canada successfully into the international technological race. In neither case, we are convinced, can excellence be imposed from outside; specifically, not by governments. So the challenge we present to the Canadian scientific

and business communities is the attainment of excellence through the exercise of their own initiative and the development of their full creative potential.

The Committee believes, however, that the Canadian government has an important complementary role to play in helping these two communities achieve excellence. It must create a better public environment for them, provide essential services, and offer adequate financial assistance. To play that part effectively, the government will have to develop a coherent overall science policy, revise its strategies and practices, and proceed with a drastic administrative reform. Although the Committee intends to deal with this last issue more systematically in a subsequent volume, we have said enough about it in this volume to indicate the dimension of the problem and the direction that its solution will take.

We are convinced that the reforms we propose will be in the best long-term interests of our country. We are also aware that our proposals will genuinely disturb some dedicated Canadians and will meet with strong resistance from government institutions that have served Canada well in the past. Our intention in putting them forward, though, was not to preserve the past, however great it may have been, but rather to prepare the future. Thus we were impressed by what Professor E. Miles of Princeton University has said about organizational problems in the American government:

> Unfortunately, governmental organizational structures and systems have a peculiar tendency always to be out of date. Organizational forms never catch up with the demands of the times. The rate of change in our society has been steadily accelerating but organizational forms are the victim of what is sometimes called "Gresham's Law of Public Administration" which says. "The pressure of day-to-day operations tends to drive out long-range planning." Stated another way, "The urgent is usually the enemy of the important." Organizational change, and to a slightly lesser degree, procedural improvement, fall under the category of matters which can be put off until tomorrow or next week or next year or until the organization is in such a bad shape in relation to the demand upon it that it is close to a crisis. It is at this point, most frequently, that reorganization occurs. But reorganizations are not usually sufficiently imaginative and drastic to cope with tomorrow's problems—only wih the worst of today's problems. Rarely is a major reorganization pattern developed and installed in a federal department or agency which is based on meeting future needs instead of merely alleviating yesterday's and today's pains. In consequence, by the time the typical reorganization is put into effect, it is already out of date.[1]

Canada is not the only country preparing to revise the targets, strategies, and administration of its science policy.

In the United States, President Nixon will probably soon announce a major shift in American science policy. On September 9, 1971 he said the United States should "find the means to insure that in this decade of challenge, the remarkable technology that took these Americans to the moon can also be applied to reaching our goals here on earth". More recently Peter G. Peterson, executive director of the President's Council on International Economic Policy, is reported to have said:

> We have to face up to the realities of the competitive world market. If we want to keep open markets and create jobs and growth, the government has got to foster—in a planned and targeted way—those industries and products that hold the promise of the best payoff in international competition. In a real sense, science and technology are being enlisted as important components of the new economic policies.[2]

To prepare the new policy, William T. Magruder has been appointed as special counsel to the President. In a letter sent out to U.S. Industry Mr. Magruder requested views "with respect to potential new technology opportunities in the civilian sector and how the Federal Government might stimulate these potential opportunities. . . . The objective is to stimulate innovation in the civilian sector of the economy directed at basic national problems and/or economic opportunities."[3] This program may eventually embrace up to 400 individual projects.[4] Its importance can be judged by the remark of a veteran science policy observer that "it now seems that Magruder is to be to technology, if not also to science, as Henry A. Kissinger is to foreign policy: the closest personal link between the President and the established bureaucracy."[5]

France too is aiming at giving the stimulation of innovation a high priority. A *National Foundation for Innovation* will be aimed at invigorating research, disseminating information and organizing conferences on innovation while the Minister of Industrial and Scientific Research, early in 1971, instituted several measures to stimulate innovation, mainly by fiscal relief to firms.[6] There is intense activity to find ways to stimulate innovation in view of France's lagging in the technological race and the requirements of international trade.

In Great Britain the government is attempting to improve the effectiveness of government R&D,[7] while the House of Commons Select Committee on Science and Technology has been considering how best to promote innovation in Britain's computer industry and published on 20 October 1971 the first volume of its report.[8]

These references show that Canada is not alone in questioning its first-generation science policy. We are probably further ahead than these other

countries in defining new targets and strategies. This is no justification for complacency, however. Indeed, Canada must make more fundamental changes than the other countries to catch up in the technological race. Moreover, while the approach we suggest is probably the only realistic one, it will necessarily be time consuming to carry out and will therefore take several years to produce its full benefits. This is why we consider the 1970s a transitional period.

But Canada has already reached the crossroads. Choices must be made now. Major decisions cannot be delayed. This nation may choose to maintain its passive attitude toward emerging world trends, let the secondary manufacturing sector of its economy gradually deteriorate, and rely mainly on the rapid depletion of its resources and its impact on services to sustain its growth. In the short term, this is the easy way, although the growing pains of manufacturing industries will be felt in the reduction in job opportunities and in a lower standard of living. In the long run, however, that choice will almost inevitably lead to an economic dead end that only annexation to the United States could delay.

The other alternative is for this country to assume the responsibility for its own destiny; to become innovative in order to strengthen its manufacturing industries; to economize and use its resources more rationally during the latter part of the century; and thus to maintain a more balanced, stable, and independent economy in the future. This may be a hard choice to make in the short term because it will require a radical change in Canadian traditions and attitudes, a major industrial conversion, which will leave temporary but significant adverse side-effects, and deep re-adjustments in the orientation and role of many private and public institutions. But in the long run, such a choice is the only rational one Canada can make.

The most crucial question is whether Canadians and their leaders now have the will to launch this new collective venture successfully. Are they prepared to put aside their vested interests, their ethnic and regional differences, their favourite ideologies, their present affluence and security, to reach a practical consensus on the shape of their future and to sustain the effort and the sacrifice that will be required to attain the objectives of the Canadian innovation operation?

This second and more difficult choice is still available. But time is running short. The 1980s may be too late to begin the operation. By then, failing the major national decisions that are required now, Canada's future will very likely have been committed to an irreversibly wrong course by default.

We intend to deal with the second generation of science policy in a subsequent volume. This covers social R&D and social innovations and is

designed to enable Canadians to improve their welfare and the quality of their lives. At present only an insignificant portion of our national R&D effort is devoted to social improvement. The targets proposed in this volume for basic research and the economic innovative process involving industry would amount to about 70 per cent of the proposed total R&D expenditures by 1980. These targets would therefore leave a large portion of the proposed total expenditures for the social innovation process by the end of the present decade. We feel that the national effort in this area should be substantially increased because of past neglect and the urgent need to improve the efficiency and control the rising costs of our social systems in such sectors as health care, pollution abatement, education, social security, housing and urban living, crime prevention, and criminal rehabilitation.

The Committee wishes to emphasize, however, that the two generations of science policy are to a large extent interdependent: more precisely, that the second depends largely on the success of the first. Indeed, if a solid foundation in basic science is not maintained, and if early decisions are not taken to promote a high flow of industrial innovations to sustain economic growth, there will not be much energy and funds left to develop a greater innovative capacity in the social area. What is more, the experience gained in correcting the deficiencies of the first generation of science policy will help in developing the second generation. At least we should not make the same mistakes.

In preparing suggestions and recommendations for social R&D and social innovations, the Committee will carefully consider how the proposals contained in this second volume are received by the public and in government circles. This too is a manifestation of participatory democracy.

NOTES AND REFERENCES

1. *Committee on Government Operations,* U.S. Congress, January, 28, 1968.
2. *National Journal,* October 23, 1971, p. 2114.
3. W. T. Magruder in letter to Dr. Philip White, in *Federal Science Trends,* Industrial Research Institute, New York, No. 58, October, 1971.
4. Deborah Shapley, in *Science,* Vol. 174, 22 October 1971, p. 386.
5. Dan Greenberg, *Science and Government Report,* Washington, October 15, 1971.
6. "France and Innovation", *Nature,* Vol. 234, November 26, 1971, p. 166.
7. A Framework for Government Research and Development, HMSO, London, November 1971, Cmmd. 4814.
8. "The Prospects for the United Kingdom Computer Industry in the 1970s", Fourth Report from the Select Committee on Science and Technology, Vol. 1, HMSO, London, October, 1971.